THE RIGHT TOOL FOR SCORING STRESS:

TESTING THE CONSISTENCY OF TWO BIOARCHAEOLOGICAL METHODS OF SCORING JOINT STRESS, OSTEOARTHRITIS AND ENTHESEAL CHANGES, IN A NORTH ALABAMA NATIVE AMERICAN SAMPLE

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# ABSTRACT

Bioarchaeologists have assumed, with limited evidence, that osteoarthritis (OA) and entheseal changes (EC) develop due to skeletal stress. To test this, the optimal study would compare OA and EC in individuals of known occupation, but few samples can support this type of study. I used a more widely applicable, underused method. I compared the rates and severity of OA and EC in four northwest Alabama prehistoric Native American populations and found that the two indicators did not co-occur consistently. Individuals with high OA or EC scores did not usually score high on both, suggesting that one or both factors are not reliable stress indicators.

## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| OA | Osteoarthritis |
| EC | Entheseal changes |
| < | Less than |
| > | Greater than |
| = | Equal to |

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# CHAPTER 1. INTRODUCTION

Human bodies are incredibly plastic, to their benefit. When a rock climber slides rope through her hands over and over, the skin doesn't shred permanently, it blisters. Over time, it grows callouses that resist further damage. Similarly, when forces outside the body put the joints under stress, they take damage but, over time, they also adapt. Unlike with blisters, these changes are visible on the bones and of great interest to bioarchaeologists.

When engineers and anatomists describe "the intensity of force acting across a particular plane," they call it stress (Currey 1984:6). Stress in bioarchaeology is the amount of force a bone is loaded with at one time, and it becomes greater the smaller the area is that the force is applied to. Because bones are subjected to varying types and strengths of stress over the course of a person's life, their response to those stresses represents a compromise adaptation; they split the difference among possible adaptations to different types of stress (Currey 1999:3288).

Stress-induced pathologies, such as osteoarthritis and entheseal changes, straddle the line in bioarchaeology between trauma and pathology. They have multifactorial etiologies, but outside stressors—traumatic forces applied to the bones—are thought to be a key factor in their development (Burt et al. 2013, Jurmain 1999, Shuler et al. 2012). This study examines the interactions between these two joint pathologies, often called stress markers, to see if one stress marker corroborates the other's findings.

Besides dental diseases, osteoarthritis (OA) is the most commonly observed pathology in the archaeological record (Weiss and Jurmain 2007:437). OA, also called degenerative joint disease, is the breakdown of cartilage between bones at the synovial joints. This leads to a host of painful changes, including the development of spurs sticking out from the bones (osteophytes), lipping of the articular surfaces, porosity, and polishing of the bone (eburnation) (Aufderheide and Rodríguez-Martín 1998:93-94, Bennett et al. 1942, Bridges 1992:68, Hough 1993). OA can be caused by several factors, with age and activity-induced trauma among the most commonly cited (Bridges 1992:68, Jurmain 1999, Plomp et al. 2013).

For the past 50 years, bioarchaeologists have been looking at OA as an indicator of occupational stress, with varying success (Angel 1964, 1966; Chapman 1962; Lovell and Dublenko 1999; Hunter and Eckstein 2009; Klaus et al. 2009; Lai and Lovell 1992; Lawrence and Sebo 1980; Lieverse et al. 2009; Lovell 1994; Molleson 2000; Jurmain 1991; Resnick 2002; Sokolof 1969; Waldron 1991a; Weiss and Jurmain 2007). Some have interpreted OA at particular joints as indicative of specific activities and have made diagnoses such as atlatl elbow, seamstress's fingers, mountaineer's gait, miner's knee, musher's knee, and golfer's big toe (Angel 1964, 1966; Bridges 1992; Burkle-de la Camp 1937; Davis 1981; Merbs 1983; Ortner 1968). However, these types of studies have been criticized for failing to give adequate weight to other possible causes of OA, such as age, genetics, and body mass (Jurmain 1999:18). Other studies have set their sights lower—rather than viewing OA as evidence of specific activities, they have tried to parse out the general activity levels of certain populations (Palmer 2012, Palmer et al. 2014). It is this latter focus that this study seeks to emulate.

In addition to looking at joint OA for evidence of activity levels, this study will examine the tendon and ligament attachment sites (entheses) around the joints. Like articular surfaces, entheses develop new bone in response to strain and repetitive activities (Herring and Nilson 1987). When people strain their muscles, the muscles tug at the tendons or ligaments attaching them to bone, causing the attachment sites to dig in and find firmer holds. The muscle's pulling action against the tendon or ligament, and that tendon or ligament's pull against the bone causes the appearance of roughened, added-on bone (Herring and Nilson 1987, Mann and Hunt 2005:203). As the entheses change their grip on the bone, they change what was once a smooth, straight attachment line (tidemark) on the bone to a jagged line, often with bony spurs called enthesophytes (Benjamin and Ralphs 1998, Benjamin et al. 2002, 2006).

Like OA studies, studies of entheseal changes (EC) have come into focus in bioarchaeology for their attempts to document activity levels in past populations (Capasso et al. 1998; Cardoso 2008; Cardoso and Henderson 2010; Cook and Dougherty 2001; Dutour 1986; Eshed et al. 2004; Hawkey 1988; Hawkey and Merbs 1995; Hawkey and Street 1992; Jurmain and Villotte 2010; Kelley and Angel 1987; Kennedy 1989, 1998; Mariotti et al. 2004, 2007; Merbs 1983; Molnar 2006, 2008a, 2008b; Rhode 2006; Villotte et al. 2010a, 2010b; Weiss 2003, 2004; Wilczak 1998). However, as is the case with OA, these studies are not without criticism, largely due to the multifactorial etiology of EC. Critiques of EC research have found many of the same confounding factors that plagued early OA studies—age, sex, body size, and genetics are all possible causes of EC in addition to occupational stress (Foster et al. 2014; Jurmain 1999; Jurmain et al. 2012; Jurmain and Roberts 2008; Mariotti et al. 2007; Vilotte et al. 2010a, 2010b). However, by accounting for the most probable confounding factors, many researchers have used EC successfully to study the levels of occupational stress experienced by archaeological populations (Campanacho and Santos 2012; Havelková et al. 2013; Milella et al. 2012; Palmer 2012; Palmer et al. 2014; Shuler et al. 2012).

Like many other studies, this one compares activity levels among archaeological populations. Unlike most studies, it analyzes both OA and EC to measure the correlation between the two lines of inquiry. If both methods accurately measure activity levels, populations with high levels of OA also should have high levels of EC. Studies that have used this technique include Palmer 2012, Palmer et al. 2014, Molnar et al. 2011, Rogers et al. 2004, Schrader 2013, and Wilczak et al. 2004. The present study also will add to sparse existing literature on EC in the prehistoric Southeast, e.g., Shuler et al. 2012.

**Theoretical Framework and Aims**

Human bones are more than the sum of their parts. An ulna is more than a dusty, lifeless artifact—it was once a vital part of someone's arm, empowering them to live out their lives as a member of their society, sometimes by performing hard work that was destructive to the very bone that enabled it. The bone might have adapted to the stress of hard labor over time, developing pathologies like OA or EC, possibly causing the person pain and limiting the work they could do. After the person died, that bone might have been buried, likely with ceremony and social meaning, only to be found hundreds of years later by an archaeologist who found enough meaning in it to excavate it and interpret its history. Following embodiment theory, this study interprets bones as social entities that integrate the material and social worlds into themselves biologically (Kreiger 2001:672). The bones convey information about pathologies, trauma, nutrition, etc., which can be used to interpret social experiences, like illness, injury, food choice, and labor (Buikstra and Scott 2009, Knudson and Stojanowski 2008). Putting the bones *in situ*, considering them not only as artifacts in an archaeological collection but as part of the social person they were part of in life, is necessary both for understanding how they contributed to past activities as well as for respecting the deceased and their descendants.

This study also follows earlier bioarchaeological activity analyses in its reliance on functional adaptation theory (a more generalized form of Wolff's Law of Remodeling[12])

[1] Wolff 1986

(Jurmain 1999:231-260, Waldron 2009:19). Simply stated, this theory is the idea that, in human bones, form follows function—when the function of a bone changes (e.g., when the person it belongs to starts using it differently or when an injury prevents the bone from functioning normally), its internal architecture and external form will change to adapt to its new function and increase its load tolerance (Benjamin et al. 2006:472, Mann and Hunt 2005:205, Sanders et al. 1995:219). Specifically, this study uses functional adaptation theory to examine 109 individuals for evidence that their bones have adapted to stress by developing OA or EC. For comparative purposes, these individuals vary in sex and age, and are drawn from four different sites in north Alabama (Long Branch, 1Lu67; Flint River, 1Ma48; Bluff Creek, 1Lu59; and Law's Site, 1Ms100) whose occupation dates range from the Archaic to the Mississippian.

This study seeks information about activity levels in several specific groups, but the larger aim of this study is to test commonly used research methods. Critiques have been raised about the validity of using OA and EC to read activities from the bones of past people, yet this practice is still common in the bioarchaeological literature (Jurmain and Roberts 2008, Jurmain et al. 2012). Likewise, critiques have been raised about which methods for recording OA and EC yield trustworthy results (Davis et al. 2013; Hawkey and Merbs 1995; Henderson et al. 2013, 2015; Villotte 2006; Villotte et al. 2010a). Due to the time constraints of a master's thesis, this study addresses the former issue but not the latter. I selected two commonly used scoring systems, one each for OA and EC, and operated under the assumption that, if both scoring systems were valid (if both recorded skeletal stress at the joints, specifically the arm joints in this study), their results would show a positive correlation with each other. For example, if OA had a high frequency in the right elbow, signaling that the right elbow was stressed in the sample, EC

[2] Wolff's Law only described adaptations in trabecular bone, but it has been used to explain changes in outer cortical bone and bone entheses (Hirschberg 2005).

would also have a high frequency in the right elbow. Another aim is to find out if OA and EC findings in earlier research that pertain to age, sex, time period, and body symmetry gain or lose support when applied to this skeletal sample.

**Hypotheses**

The hypotheses guiding this study are as follows:

(1) OA and EC will show significant correlation with each other. Studies have found significant, though not always direct, relationships between OA and EC after adjusting for age and sex (Molnar et al. 2011:288; Rogers et al. 2004). Some have interpreted this as evidence that mechanical stress can cause OA (Rogers et al. 2004).

(2) OA and EC also are likely to be associated with increasing age. The idea that aging bodies have more OA and EC is common in both the clinical and bioarchaeological literature (Durigon and Paolaggi 1991; Milella et al. 2012; Molnar et al. 2008a, 2008b, 2011; Nagy 1998; Niinimäki 2011; Robb 1998; Shuler et al. 2012; Villotte et al. 2010a:229).

(3) Mississippian individuals will likely display more OA and EC than pre-Mississippian individuals. Agriculturalists in the Southeast previously have been found to display more OA and EC than hunter-gatherers (Bridges 1989b, 1991a; Havelková et al. 2010; Shuler et al. 2012;).

(4) The presence or absence of OA and EC is not expected to vary significantly by side of the body. Findings in the literature on asymmetry are mixed. Bridges (1989a, 1991b) found bilateral asymmetry in Pickwick Basin populations, but she later (1992) found less asymmetry than expected. Other researchers have found no significant asymmetry (Palmer 2012, Palmer et al. 2014, Shuler et al. 2012).

(5) Instances of OA and EC likely will show significant variation by sex. Variation in OA by sex has been documented (Pfeiffer 1977, Waldron 1991b), as has variation in EC (Eshed et al. 2004; Churchill and Morris 1998; Molnar et al. 2011; Weiss 2003, 2004; Weiss and Jurmain 2007; Wilczak 1998; Shuler et al. 2012).

# CHAPTER 2. BACKGROUND

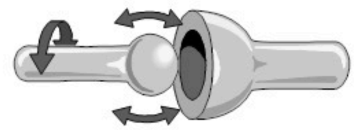
## Joint Anatomy and Biomechanics

Joints are the focus of this study; they are defined as those areas where two or more bones meet (Palastanga et al. 2006:24). In particular, this study will examine the ways joints respond to occupational stress and how bioarchaeologists interpret these responses. However, understanding what stresses the joints to the point of injury requires an understanding of how they function normally. This chapter will focus on the shoulder and elbow joints and the anatomical features of those joints that are relevant to the present study (for comprehensive joint anatomy, see Gest and Schlesinger 1995 or Palastanga et al. 2006). It will familiarize the reader with the functional and structural anatomy of healthy synovial joints, the effects joint components have on articular surfaces and entheses, and relevant advances in joint-related scholarship.

**Anatomy of healthy joints—function.** When joints are classified by their function, the shoulder and elbow are fairly simple. The shoulder contains two joints. The topmost is the acromioclavicular joint, a gliding joint (figure 1) that allows the acromion of the scapula to slide on one plane against the lateral end of the clavicle. This allows the arm to rise above the head and lower toward the body. The other shoulder joint is the glenohumeral, a ball-and-socket joint (figure 2) that connects the scapula's cup-like glenoid fossa to the ball-shaped head of the humerus. The joint's shape allows the humeral head to rotate freely within the glenoid fossa, allowing the shoulder to flex the arm in front of the body, extend it down and back, adduct it across the body, and abduct it toward the head (Gamble 1988).

**Figure 1**. Movement in a gliding joint (Amato 2013)

**Figure 2.** Movement in a ball-and-socket joint (Amato 2013)



The elbow contains both hinge and pivot joints. The humeroulnar joint, which articulates with the trochlea of the distal humerus to the olecranon process of the proximal ulna, and the humeroradial joint, which articulates with the capitulum of the distal humerus to the radial head, are both hinge joints (figure 3). They allow the forearm to flex in toward the upper arm and then to extend outward. The elbow also contains a pivot joint (figure 4), the proximal radioulnar joint. This connects the radial head to the radial notch of the ulna, allowing the radial head to roll slightly backward when the hand moves from the supine to prone position, and freeing the distal radius to cross in front of the ulna. Ligaments, slightly elastic collagen fibers, connect each of these joints' bones to each other, which stabilizes them; tendons, flexible tissue bands, provide further stability by attaching muscles to the bones (Palastanga et al. 2006, Gamble 1988).

**Figure 3.** Movement in a hinge joint (Amato 2013)

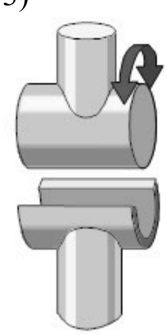
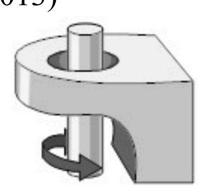
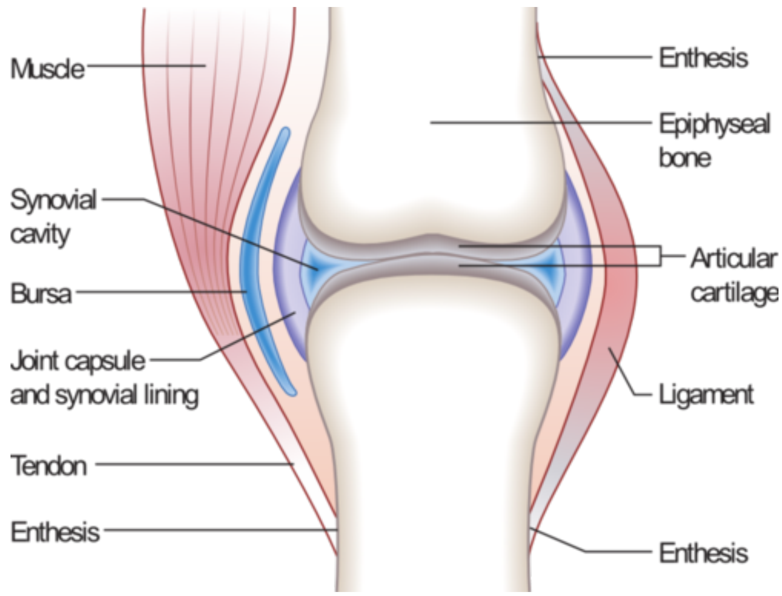


**Figure 4.** Movement in a pivot joint (Amato 2013)



**Anatomy of healthy joints—structure.** When joints are classified structurally, they become increasingly complicated; however, the specific structure of synovial joints is worth spending time on because it is the reason the joints degrade the way they do. It exposes their vulnerabilities to overuse injuries, such as arthritis and entheseal changes.

**Figure 5.** Basic synovial joint structure (Summit 2015)




Structurally speaking, the shoulder and elbow joints are both synovial (figure 5). This means that they are freely movable (diarthrotic) joints. These joints are composed of two or more bones, articular cartilage (on the surfaces of the bones where they rub together), and a fluid-filled synovial cavity between the bones (Palastanga et al. 2006). The fluid is a blood filtrate (with the consistency of raw egg whites), which serves to lubricate the joint (Mosby's Medical Dictionary 2017:1725). An inner synovial membrane and an outer fibrous capsule (made of connective tissue) wrap around the joint and connect to both of the bones at the outer boundaries of the joint capsule. Ligaments connect the bones together, while tendons connect the bones to the muscles that move them. When overuse causes the ligaments or tendons start to fail, they can either tear away from the bone suddenly (called a rupture or avulsion, resulting in the muscle retracting away from the tear and a loss of muscle function), or they can fan out their fibers to distribute force more widely (Benjamin et al. 2002:932). In the case of overuse, the point where the ligament or tendon connects to the bone (the enthesis) changes. An entheseal change might act to strengthen the enthesis by building up extra bone (osteophytes or enthesophytes), or might weaken it (causing cysts, worn away bone, porosity, etc.) (Benjamin et al. 2002, Burt et al. 2013:4-5).

Another important point about entheses is that they come in two major types based on the type of tissue at the site of skeletal attachment, fibrous and fibrocartilaginous. Fibrous entheses in the limbs usually attach to the diaphysis (or shaft) of a bone, while fibrocartilaginous entheses typically attach to an epiphysis (end) or an apophysis (bony outgrowth, such as a process, tubercle, or tuberosity) (Benjamin et al. 2002:934). This study will only consider fibrocartilaginous entheses because anatomists view them as more susceptible to overuse injuries and they are more thoroughly understood (Benjamin et al. 2002:934, Weiss 2015).

**The shoulder**. In the shoulder, at the acromioclavicular joint, four ligaments connect the clavicle to the scapula (figures 6 and 7). These include the trapezoid and conoid ligaments (also called the coracoclavicular ligaments), which run from the clavicle's oblique line to the scapula's coracoid process. The scapula is also stabilized by a ligament linking its acromion and coracoid process, the coracoacromial ligament. At the space where the acromion and the distal clavicle meet, a fibrous joint capsule houses articular cartilage, synovial fluid, an articular disc, and synovial membrane. The acromioclavicular ligament (figure 7) sits outside the joint capsule, connecting the distal clavicle to the acromion. A bursa just beneath the joint capsule provides cushioning between the acromion and the tendons below it (Palastanga et al. 2006, Gamble 1988).

Important tendons at this joint include the origin of the long head of the biceps, which attaches to the scapula's supraglenoid tubercle, the origin of the short head of the biceps, which attaches to the scapula's coracoid process, and the origin of the long head of the triceps, which attaches to the scapula's infraglenoid tubercle. The biceps muscle serves to flex and supinate the forearm and elbow, as well as rotate the hand laterally, while the triceps extends the shoulder, forearm, and elbow. The deltoid muscle attaches to the spine of the scapula and the clavicle's deltoid tubercle, and extends down to the deltoid tuberosity on the humeral shaft; it causes the arm to flex, rotate medially, abduct, extend, and rotate laterally (Palastanga et al. 2006, Gamble 1988).

Lower in the shoulder, at the glenohumeral joint, the humerus connects to the glenoid fossa of the scapula via a fluid-filled, cartilage-encased articular capsule. Several tendons surround the joint capsule to attach to the greater tubercle of the humerus, including those leading to the supraspinatus, the infraspinatus, and the teres minor. Their muscles stretch across the anterior scapula. The tendon leading to the subscapularis attaches to the lesser tubercle and stretches across the posterior scapula. These tendons form a group called the rotator cuff, which reinforces the glenohumeral joint capsule. The supraspinatus muscle abducts the arm, the infraspinatus and the teres minor rotate the arm externally, and the subscapularis rotates the arm internally (Palastanga et al. 2006, Gamble 1988).

**Figure 6.** Acromioclavicular joint ligaments (Elsevier 2017)

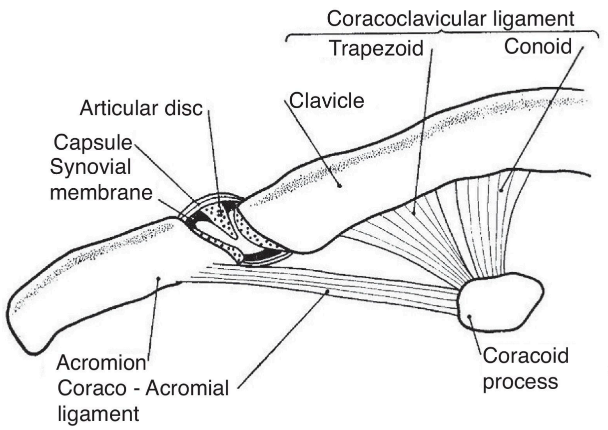
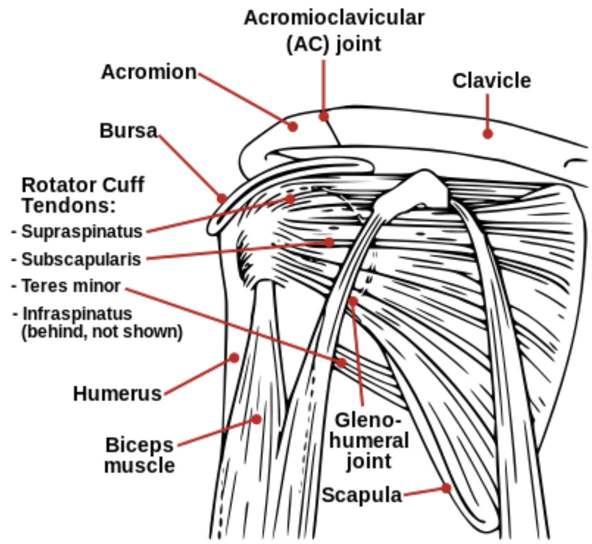


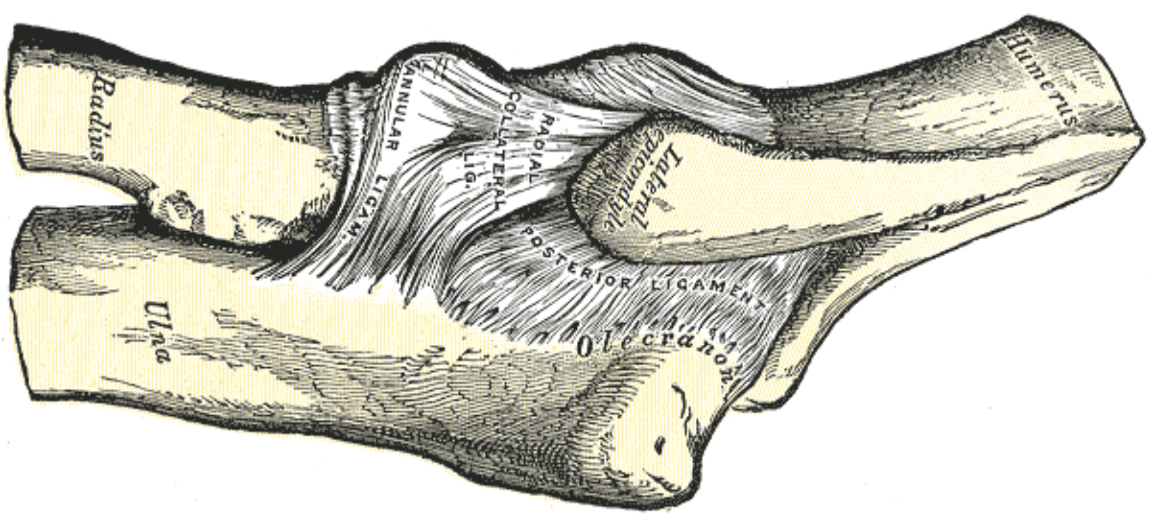

**Figure 7.** Glenohumeral joint tendons (NIAMSD 2006)




The most common shoulder injuries include dislocation, separation, rotator cuff disease, rotator cuff tear, frozen shoulder, fracture, and arthritis (NIAMSD 2014). Degradation of the glenohumeral joint, specifically, is associated with rotator cuff damage for older adults and with overhead throwing in younger adults (Resnick 2002, Waldron 2009). The shoulder is also particularly vulnerable to acromioclavicular sprains and instability in the glenohumeral joint (Quillen et al. 2004). Another common problem is injury to the supraspinatus muscle and tendon, which is often pinched because it lies between two bony surfaces, the head of the humerus and the acromioclavicular joint. This can be caused by acromioclavicular joint arthritis, weak rotator cuff muscles, calcification of the coracoacromial ligament, or an abnormally shaped acromion (Fongemie et al. 1998).

**The elbow.** At the elbow, the humeroulnar and humeroradial joints (figure 8) are composed of articular cartilage, which surrounds the trochlea and capitulum (at the distal end of the humerus). This is encased by a fluid-filled synovial cavity, synovial membrane, and fibrous articular capsule. A bursa provides cushioning on the posterior side of the capsule. The radioulnar joint (figure 8) is formed where the proximal radius and ulna meet, at the radial head and the radial notch of the ulna. On the anterior side of the joint capsule, the annular ligament connects the proximal radius and ulna by crossing over the radial head to the ulnar tuberosity. The quadrate ligament performs a similar function by connecting the radius and ulna on their medial sides, just below the radial head and trochlear notch. On the distal side of the joint, the radial collateral ligament connects the ulnar tuberosity to the lateral epicondyle of the humerus, adding stability to the joint. On the medial side, the ulnar collateral ligament connects the medial epicondyle of the humerus to the ulna's coronoid process, trochlear notch, and olecranon process (Palastanga et al. 2006, Gamble 1988).

**Figure 8.** Humeroulnar, humeroradial, and radioulnar joints (Gray 1918)




Several tendons and their associated muscles attach at the elbow. The common extensor tendon attaches the extensor carpi radialis brevis, extensor carpi ulnaris, extensor digiti minimi, and extensor digitorum at the lateral epicondyle of the humerus. These posterior forearm muscles extend the wrist and hand, as well as abducting and adducting the hand. The common flexor tendon attaches the pronator teres, flexor carpi radialis, palmaris longus, flexor digitorum superficialis, and flexor carpi ulnaris muscles to the anterior side of the forearm at the medial epicondyle. These muscles pronate the forearm, flex the wrist and hand, and abduct and adduct the hand. Another muscle in this area is the biceps brachii, which inserts at the radial tubercle; it serves to flex the forearm and flex and supinate the arm. The brachioradialis inserts at the radial styloid process and serves to flex the elbow, as well as assisting in elbow pronation and supination. At the ulna, the triceps brachii inserts at the olecranon process. It extends the forearm and extends and adducts the arm. The ulnar tuberosity provides the insertion point for the brachialis, which flexes the forearm (Palastanga et al. 2006, Gamble 1988).

The most common elbow injuries include lateral epicondylosis or tennis elbow (injury to the common extensor tendon), medial epicondylosis or golfer's elbow (injury to the common flexor origin), biceps and triceps tendon abnormalities, medial ulnar collateral ligament injuries, and lateral collateral ligament injuries (Hayter and Adler 2012).

**OA and EC development.** OA and EC are widely viewed as bony modifications caused by repetitive stress on muscles, tendons, and ligaments (Benjamin et al. 2002, Kennedy 1989, Shuler et al. 2012, Villotte et al. 2010a). Osteophytes, in particular, are thought to widen a joint's load-bearing surface in order to provide added stability (though they often also limit joint movement) (Burt et al. 2013:5). At this point, OA and EC due to a single traumatic event cannot be differentiated visually from OA and EC due to an extended pattern of overuse or pathology (Meyer et al. 2011:203). It is likely, however, that most wear-related joint pathologies noted by bioarchaeologists as primary OA or EC are the result of extended overuse rather than a single event. This is because a single-event trauma to a joint that is severe enough to cause entheseal changes would normally leave evidence of other changes to the bone, such as a fracture, dislocation, or periostitis, and would be noted as secondary OA or EC. In either case—an intense, single event trauma or repetitive stress—an overload of mechanical stress to the joints causes micro-trauma to the articular surfaces and/or entheses, changing their tissue structure (Villotte and Knüsel 2013). For OA, this trauma causes excess porosity, osteophyte development, eburnation, and/or ankylosis[3] (Buikstra and Ubelaker 1994:122-123). For EC, it causes irregular tidemarks[4], vascularized fibrocartilage, calcified soft tissues, and/or enthesophytes (Villotte and Knüsel 2013:140).

**Joint Disease in Biological Anthropology, Evolving Viewpoints**

Biological anthropologists have studied joint stress since before bioarchaeology was named its own subfield in 1977 (Angel 1964, 1966; Buikstra 1977; Burkle-de la Camp 1937; Chapman 1962; Ortner 1968; Sokolof 1969). However, often their interpretations were criticized for reading specific past activities from signs of joint degradation without adequately considering the multifactorial etiology of OA (Jurmain 1999, Jurmain et al. 2012). In fact, Jurmain and colleagues (2012), who themselves spent decades researching OA, report that the quality of OA research has declined over the past 10 years.

Studies of entheseal changes (EC) in archaeological populations have followed a similar pattern. The earliest studies appeared around 1900, e.g., Testut 1889, but behavioral reconstructions from EC did not gain momentum in bioarchaeology until the 1960s and 1970s

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[3] Ankylosis the fusion of two or more normally mobile bones in a joint, which renders the joint immobile; White et al. (2012:577) define it as "an abnormal, complete immobility or fixation of a joint, resulting from pathological changes in the joint"

[4] A tidemark is the line in a fibrocartilaginous enthesis where uncalcified fibrocartilage meets calcified fibrocartilage (Benjamin et al. 1986, Villotte and Knüsel 2013:136).

(Angel 1966; Hawkes and Wells 1975; Wells 1963, 1964, 1965). As with OA, when EC studies gained popularity, many researchers succumbed to over-interpretation. As Jurmain et al. (2012) point out, even the early terms for EC—activity-induced pathology (Merbs 1983), evidence for occupation (Kelley and Angel 1987), skeletal markers of occupational stress (Kennedy 1989), and activity-induced stress markers (Hawkey and Street 1992)—suggest that EC provide clear evidence of activities or occupations. More recently, researchers have begun to focus on better accounting for confounding factors (such as age, sex, other pathologies, and genetic differences) that could be contributing to OA and EC development (Jurmain et al. 2012).

The vast amount of bioarchaeological and paleopathological literature on OA and EC makes a thorough review impractical for a master's thesis (Meyer et al. 2011:204 described the quantity of OA literature as "almost unmanageable"). In light of this, several of the most influential early OA and EC studies will be discussed here, as well as major critiques and more recent literature.

**Early OA research.** Angel's 1966 study of a site near Tranquility, California, produced the first OA study to gain major attention in biological anthropology. He suggested that the elbow arthritis he found in males was the result of "vigorous" atlatl use and in females was due to seed grinding (Angel 1966:17). He and his associates built on this work in later research, linking localized arthritis to specific activities, such as horseback riding, heavy labor, digging, and specific occupations, such as weaver, laundress, and skilled craftsman (Angel 1971, Angel et al. 1987, Kelley and Angel 1987).

Orner (1968) followed Angel in finding elbow OA and attributed it to the atlatl. He found elbow OA more frequently in the Eskimos he studied than in the Peruvians, and because Eskimos used the atlatl and Peruvians did not, he reasoned that that atlatl was the primary cause.

Another early study with major impacts is Merbs's 1983 study on the Sadlermiut Inuit population in Canada. He used archaeological, historical, and comparative data on other Inuit groups to reconstruct the Sadlermuit's day-to-day activities. From there, he analyzed the group's arthritis patterns and attributed the women's OA to processing hides for clothing and the men's OA to throwing harpoons and paddling kayaks. He attributed right elbow OA, regardless of sex, to use of the metate, a stone tool for grinding. He also analyzed vertebral osteoarthritis (more commonly called vertebral osteophytosis, or VOP), which he suggested was due to sledding, for women, and carrying heavy loads, for men.

Several other studies focused on elbow arthritis, including Pickering (1984) and Miller (1985). Pickering's study was one of the earliest to cast doubt on the clear-cut relationship between OA and specific activities. He compared OA in a prehistoric Archaic group of Native Americans from Illinois that used the atlatl to a later Mississippian group that used the bow. Although he expected to find that males in the atlatl group expressed the most arm OA and bilateral asymmetry of OA in the arms, Pickering actually found no difference in arm OA between atlatl and bow groups. Also contrary to expectations, he found more bilateral asymmetry in females (who were not thought to have used the atlatl for hunting) compared to males. Similarly, Miller (1985) predicted that the elbow OA he found at a Pueblo Indian site (Nuvakwewtaga) would be attributable to grinding maize with the mano and metate, which was done by women; however, the data did not support his predictions. Males and females had similar levels of elbow OA.

OA often was interpreted as a result of horseback riding in the 1970s and 1980s. Bradtmiller (1983) compared OA in prehistoric and historic Arikara groups in an attempt to find changes in the skeleton that might be due to the introduction of the horse in North America.

Although he found no more OA in historic Arikara groups than in prehistoric groups, he found that the pattern of OA in the historic groups was reflective of horseback riding. They had more OA in the vertebral column, sacroiliac joint, hip, knee, and ankle. He attributed the lack of difference in his study to age variation between samples. Edynak (1976) performed a similar study to look at the effects of horseback riding on the body. He looked at groups around the world that rode horses and found increased arthritis prevalence in the pelvic and lumbar joints as compared to groups that did not ride horses.

**OA criticism.** In the 1990s, the behavioral studies that gave promise to early OA research in bioarchaeology began to take criticism for failing to give adequate weight to other possible causes of OA, such as age, genetics, and body mass, and for employing circular reasoning to support their conclusions (Jurmain 1999:18, Jurmain and Kilgore 1995). Likely as a result of these criticisms, OA studies became noticeably less common by the late 1990s (Weiss and Jurmain 2007).

As early as 1995, Jurmain and Kilgore began critiquing OA studies (including some of Jurmain's earlier studies in 1977 and 1980), and the former has remained a consistent watchdog over OA research. Jurmain collaborated with Weiss in 2007 to review the literature on OA. The pair described recent developments from the clinical literature on the causes of OA (including age, genetics[6], anatomical variation, and body mass) and critiqued several studies for not taking into account the multiple causes of OA (Weiss and Jurmain 2007). They pointed out that any sex differences in OA prevalence and severity may not be the result of sexual division of labor, an

[6] See also Jurmain (1999:62-63) for a summary of several genetic causes of bone turnover and Rogers et al. (1997) for a discussion of their theory of "bone formers," people who have above average rates of osteophyte and enthesophyte development due to genetic factors.

explanation that many anthropologists have gravitated toward, but may be more related to differences in hormones, body size, genetics, and anatomy.

Other criticisms came from Meyer et al. (2011). Their review of the OA literature led them to critique what they viewed as insufficient sample sizes, conclusions based on too little evidence, and disregard for other possible causes of OA in previous studies. They recommended that OA researchers exercise greater care in their study designs, and, if they wished to discuss specific activities, that they use indicators other than OA to do so (such as tooth abrasions from clay pipe smoking, clay-shoveller's fractures to the vertebrae, and auditory exostoses).

**OA resurgence.** Since around 2000, many OA studies have set their sights lower, and that has garnered considerably less criticism. Rather than viewing OA as evidence of specific activities, they have tried to parse out the general activity levels of certain populations (Palmer 2012, Palmer et al. 2014). They also have begun incorporating newer methods of EC analysis into their studies.

Molnar et al. 2011 exemplifies some of the more recent OA research. In their study of two Middle Neolithic samples from Gotland (n=78), they found increased OA and increased EC to be highly correlated with increased age. They found higher OA levels in females and higher levels of EC in males.

Palmer et al. (2014) follow Palmer's earlier work (2012) in combining OA and EC analysis within the same study. In the 2014 study, the authors describe 69 individuals in a 19$^{th}$ century Dutch cemetery where dairy farming is known to be a prevalent occupational activity. They found that most of the population was physically active, but there were not enough differences in physical activity to divide out a less active social class. Males were found to have larger muscle attachments than females (especially for the biceps brachii). The authors attribute this to a sexual division of labor in which males did more pushing or pulling while their elbows were flexed. The authors found the correlation between OA and EC to be very low.

Nagy (2000) also combines OA and EC analysis. She examines samples from two Kentucky groups, one group of Late Archaic hunter-gatherers and one group of late prehistoric agriculturalists. She found strong evidence of sex differences, which she suggests are due to the sexual division of labor. She also found that males were more mobile than females and used their upper bodies for more strenuous activities. There was also difference between the groups, suggesting that different subsistence strategies led to different daily activities.

**OA research in the southeastern United States.** In the Southeast, one of the most prolific OA researchers was Patricia Bridges. She published four articles and a book section about OA in the Southeast (1985b, 1989a, 1989b, 1991a, 1991b), as well as an article on OA in the Americas more generally (1992). Her works that are most pertinent to this study are her studies from 1989(b) and 1991. In her 1989(b) study, she records bone size, strength, and asymmetry for Archaic hunter-gatherers and Mississippian agriculturalists. Bridges found that the long bone diaphyses of Mississippians were more robust than those of Archaic individuals, which suggests that the agriculturalists were undertaking more strenuous activities. Further, she found more robust arms in Archaic females than in Mississippian females (especially near the elbow on the left side of the body), likely due to flexion and extension at the elbows of both arms. For males, Mississippians had more robust femora than Archaic individuals but similar humeri.

In Bridges's 1991 study (published as a dissertation [1985a], journal article [1985b], and book chapter [1991b]), she examined appendicular OA in 140 Archaic hunter-gatherers and 126 Mississippian agriculturalists from Alabama's Pickwick Basin. She found a similar prevalence of

OA between Archaic individuals and Mississippians. For a few joints, the people from Archaic groups displayed slightly higher OA levels that the Mississippians (though she notes that this could be due to the Archaic group in the sample being slightly older). She determines that the activity levels between the groups were similar.

In a comment on Bridges's 1989 and 1991 work, Knüsel (1993) argues that she does not go far enough in her analysis. He points out that two of Bridges's results seem contradictory. She finds that hunter-gatherers have higher (though not significantly higher) levels of OA than agriculturalists, suggesting that their work was more physically demanding; of the agriculturalists, men have more OA than women. Another confusing result is that agriculturalists have greater bone robusticity than hunter-gatherers, suggesting that agriculturalists strained their musculoskeletal systems more than hunter-gatherers. Knüsel attributes these conflicting results to the ages at which children in each society started working alongside adults. He hypothesizes that, if children begin working alongside adults at a young age, their bodies will be less vulnerable to work-related injuries later in life. Based on Bridges's data, Knüsel posits that agriculturalists begin working as adults at an earlier age than hunter-gatherers, and that females are the first of the agriculturalist group to work, from which they build up "bone memory" (Knüsel 1993:524).

Other studies of OA in the Southeast, including one from Georgia, have concluded that long bone size, strength, and osteoarthritis decreased from the Archaic to the Mississippian, suggesting that workloads decreased with the rise of agriculture and later increased in the late contact period (Larsen 1980, Larsen 1996). Another study of prehistoric Georgians (Williamson 2000) compared quantities of OA between groups from different physiographic provinces in Georgia. In his sample of 81, he found that upland males had more OA than females and that upland males and females had higher rates of OA than their counterparts in coastal environments. He suggests that this is to be expected when the body must respond to varying terrain and carrying objects uphill.

In another Southeastern OA study (of 72 individuals), Lubsen (2004) found that Archaic females from northwest Alabama had two to three times as much OA in their arms as Archaic males. He attributed this to the repetitive work of processing foods like nuts, seeds, and mussels. Males were found to have more OA in the pelvis, knee, ankle, and foot due, according to Lubsen, to long-distance travel for hunting, resource gathering, and trading.

**Beginnings of EC research.** Studies of entheseal changes (also known as musculoskeletal stress markers, occupational stress markers, activity-induced stress markers, musculoskeletal attachment sites, enthesiopathies, and activity-induced pathologies) have recently come into focus in bioarchaeology for their attempts to document activity levels in past populations (Capasso et al. 1998; Cardoso 2008; Cardoso and Henderson 2010; Cook and Dougherty 2001; Dutour 1986; Eshed et al. 2004; Hawkey 1988; Hawkey and Street 1992; Hawkey and Merbs 1995; Jurmain and Villotte 2010; Kelley and Angel 1987; Kennedy 1989, 1998; Mariotti et al. 2004, 2007; Molnar 2006, 2008a, 2008b; Rhode 2006; Villotte et al. 2010a, 2010b; Weiss 2003, 2004; Wilczak 1998).

One of the earliest EC studies in bioarchaeology was run by Dutour, who examined EC in samples from two Neolithic populations from separate regions of the Sahara (1986). He found EC in 20% of the sample, with most of the changes near the elbow and in the feet. Dutour suggested that javelin throwing, wood-cutting, and archery had caused the elbow EC and that repeated walking and running over hard ground had caused the foot EC.

Another early EC study was that of Hamilton (1982), which examined the deltoid tuberosity of the humerus among Mississippian groups in the Lower Illinois River Valley. Hamilton found greater quantities of EC in females as compared to males, which he believed were due to changing methods of food production.

**EC criticism.** As is the case with OA, these studies are not without criticism, largely due to over-interpretation and a multifactorial etiology. Critiques of EC research have found many of the same confounding factors that plagued early OA studies—age, sex, body size, and genetics are all possible causes of EC in addition to occupational stress (Foster et al. 2014; Jurmain 1999; Jurmain et al. 2012; Jurmain and Roberts 2008; Mariotti et al. 2007; Vilotte et al. 2010).

Some authors, such as Hawkes and Wells (1975:118-22), extended their interpretations of entheseal changes far past where their critics thought the data allowed. In their 1975 study of an Anglo-Saxon cemetery, Hawkes and Wells deduced from a single exostosis on a femur, in conjunction with a prone burial position and a lack of clothing remains, that a teenaged girl was a rape victim.

A similar case study built on scant evidence was conducted by Oates et al. (2008); it describes a person the authors call an acrobat; this distinction is based on what they viewed as evidence of jumping and twisting movements (OA on the humeral head and the patellae and enthesophytes on the tibia and calcaneus). Jurmain and Roberts (2008) were quick to criticize what they viewed as overly specific occupational interpretations, especially given that the skeleton was incomplete.

Villotte and Knüsel (2012) provided a critique of Godde and Taylor (2011) based on the latter pair’s failure to take age into account in their EC study, which they describe as the primary parameter that EC studies should control for. Godde and Taylor examined EC in a sample of 108 individuals with known activity levels and body mass indexes (BMIs). They attempted to tie EC to activity level and BMI so reliably that a person's activity level and BMI two could be predicted from their EC in forensic contexts. Villotte and Knüsel asserted that, because Godde and Taylor failed to restrict age-at-death in their study (and also failed to report the age distribution in their subgroups), that the study's conclusions are unreliable.

Niinimäki (2011) critiqued several studies of EC and activity patterns that include older individuals. She documented EC in 108 individuals of known age, sex, and occupation in Finland. She found age and muscle size to be the most significant causes of EC. Because muscle attachment sites grow with age, Niinimäki (2011:292) concluded that "labor intensity cannot be reliably recorded in old individuals." So, researchers should take both age and body size into account, she reports, before using EC to make judgments about labor intensity.

**EC resurgence.** By accounting for the most probable confounding factors, many researchers have used EC successfully to study the levels of occupational stress experienced by archaeological populations (Campanacho and Santos 2012; Havelková et al. 2013; Milella et al. 2012; Palmer 2012; Palmer et al. 2014; Shuler et al. 2012).

Villotte et al. (2010a) examined the upper limbs of 37 European Upper Paleolithic human fossils. They found that EC in the upper limbs were less prevalent in the foraging group and it was males as opposed to females who had unusually high rates of EC to the right medial epicondyle of the humerus. Based on similarities between the observed EC and those acquired by javelin throwers (as reported in sports medicine research), the authors suggest that the four males with EC to the medial epicondyle participated in habitual throwing activities. Although these authors do divide the sample into sex cohorts and eliminate anyone over age 50, the sample size is quite small. Therefore, this study's results may be viewed as preliminary.

To test the correlation between EC and bone cross-sectional properties, Niinimäki (2012) assessed the torsional/average bending rigidity of four locations on the humerus and recorded the extent of EC at four entheses on the humerus for two English populations and one 20th century Finnish population. She controlled for age by dividing her sample into age cohorts (<40 and ≥ 40) and split her sample by sex to account for possible sex-based size differences and hormonal differences. Niinimäki also controlled for genetic influence by drawing a reasonably sized sample from each cemetery, on the assumption that the individuals within a given cemetery would be genetically similar. She also created a standardized score for humeral length to enable her to measure absolute variation. Overall, Niinimäki found low to moderate, though significant, correlations between EC and torsional rigidity in the sample; for males, the correlation was stronger.

**EC research in the Southeast.** EC research on prehistoric skeletal remains from the Southeast has been sparse (one such study exists, Shuler et al. 2012). Shuler et al. (2012) examined the upper limb fibrocartilaginous entheses of 159 individuals from Moundville and its outlying settlements. They found a greater frequency of EC in Mississippian agriculturalists as compared to Late Woodland hunter-gatherers. The most frequently changed entheses were those used to flex the arm, which the authors attribute to a resurgence of large game, such as deer, and maize domestication. Males at Moundville, particularly young males, were 26 times more likely than males from satellite settlements to experience EC at the elbow extensor muscles and 12 times more likely to experience EC at the site of the brachialis muscle. Females at Moundville had more EC to the biceps muscle insertions and common extensors of the humeri.

**Significance of this study.** This study aims to make significant contributions both to specific bioarchaeological problems and to related fields. One specific contribution is that it will double the current studies on upper limb entheseal changes in the prehistoric Southeast. Shuler et al. (2012) published on entheseal changes on prehistoric Native American individuals from ten sites in the Tennessee-Tombigbee region of Mississippi and Alabama; however, nothing has been published on entheseal changes in northern Alabama. This study also contributes to the bioarchaeological literature in a salvage capacity. The four sites being studied will be repatriated under NAGPRA in the immediate future. In order to avoid losing this data, it is vital to document joint pathologies in the skeletal remains of individuals from these prehistoric sites while they are still accessible.

Further, any work that makes bioarchaeological findings more reliable also advances scholarship in related fields that incorporate bioarchaeological data into their research. In archaeology, bioarchaeological data provides insights into the lifestyles of a site's ancient occupants and into their embodied social experiences. Knowing the potential and limitations for interpreting wear-based skeletal changes affects how archaeologists interpret their sites overall. Anatomists are affected by advances in OA or EC research because bioarchaeological research can test some of their theories about joint degradation on a more diverse sample. By applying the theories to past populations, which had different social and environmental pressures on them in life compared to modern populations, anatomists can get a better view of how joints degrade in different circumstances.

**Lessons from the literature.** This study uses critiques of earlier OA and EC studies as a guide for methodological problems to avoid. Some of the harshest critics of OA studies, Jurmain et al. (2012), provide several suggestions for future research on activity patterns that this study will adhere to. The first suggestion is to account for age, as increasing age is the variable most highly correlated with increasing OA (Villotte et al. 2010a, Weiss and Jurmain 2007). To account for age, I will estimate age at death for the individuals using standard aging methods (e.g., Buikstra and Ubelaker 1994). I will then divide my sample into two age cohorts, 18 to 34 years and 35 to 50 years. It is known that age-related osteophyte development begins after about age 35 and then accumulates rapidly after 50 (Cooper et al. 1994). With separate age cohorts, few to no osteophytes that are age-related should appear in the younger group, and these osteophytes will be limited in the older group.

Age-related EC begins developing in tendons between ages 30 and 35 as tendon blood vessel, water, collagen, and glycoprotein quantities decrease (Bard 2003, Rodineau 1991). Ideally, the younger age cohort would cap at 30 years to minimize the age-related EC found. However, in the interest of maintaining a sufficient sample size in the younger cohort and to keep the age cohorts the same for both OA and EC analysis, the cap was set at age 34. Another age-related EC happens at about age 60 when tissue is disrupted in the fibrocartilaginous entheses, causing changes to the skeleton (Alves Cardoso and Henderson 2010, Villotte et al. 2010b). The second age-related EC will fall outside the upper limit (age 50) of the older age cohort in this study and should not affect results. Although many age-related ECs can be accounted for, rates of bone remodeling can vary from individual to individual, making it impossible to account for all age-related ECs. Still, the effects of age-related EC on this study's result are expected to be minimal.

Jurmain et al. (2012) and Weiss and Jurmain (2007) suggest grouping samples by sex, as differing body sizes and sex hormones have been suggested to impact rates of OA and EC development; this study will follow that suggestion.

It has been suggested that genetic variation may play a role in OA and EC development and that samples should be as genetically homogeneous as possible (Jurmain et al. 2012, Meyer et al. 2011). Thelin et al. (2004), for example, found an increased risk of OA for family members of farmers with OA. There are known disorders in modern people that can cause OA, such as Stickler syndrome, which involves a mutation on a collagen-producing gene (Kliegman et al. 2007). Unfortunately, samples of genetic material cannot be cut out of the bones in this study due to NAGPRA restrictions on destructive analysis.

Weiss and Jurmain (2007) further recommend collecting data on asymmetry for multiple variables (e.g., OA, EC, cross-sectional geometry, and body size) as this type of information can yield information on activity patterns. This study will collect and analyze bilateral asymmetry data for every joint surface and enthesis being studied.

**Prehistoric Alabama: Pre-Mississippian and Mississippian Periods**

**Site choice.** Individuals from four archaeological sites will be examined in this study: Long Branch (1Lu67), Flint River (1Ma48), Bluff Creek (1Lu59), and Law's Site (1Ms100) (Webb and DeJarnette 1942, Webb 1939, Webb and Wilder 1951). The sites were chosen for their temporal variability, geographic proximity to each other, and limited accessibility for future research. Sites that were active during different time periods (from the Late Archaic to the Late Mississippian) around the transition to agriculture were chosen for this study to allow for period comparisons, including comparisons of hunter-gatherers versus agriculturalists. To limit the confounding factors that might come with disparate climates and geography, sites were selected that have similar climates and fall within a relatively small geographic area. All of the sites are on the banks of the Tennessee River in extreme north Alabama and all are within a 60-mile radius of each other. The sites also were selected because they are slated for repatriation within the next two years. They will be impossible to access for future research.

**Pre-Mississippian periods.** The Archaic period in the Southeast stretched from roughly 10,000-3000 BP and can be broken down into three periods, the Early (10,000-8000 BP), Middle (8000-6000 BP), and Late Archaic (6000-3000 BP) (Steponaitis 1986). Other dates have been calculated for north Alabama specifically. The Early Archaic stretches from 11,450 BP to 1900 BP, the Middle Archaic from 8900-5700 BP, and the Late Archaic from 5700-3200 BP (DeVore 2013).

Early Archaic groups in the Southeast are characterized by their relatively smaller territories and denser settlement patterns than earlier Paleoindian groups. Projectile points and the atlatl also emerged in this period. In the Middle Archaic, groups became increasingly sedentary as they began eating marine foods, including fish and mollusks. In the Late Archaic Southeast, groups largely remained sedentary and began creating mounds and middens, as well as new types of tools. In the Archaic as a whole, a loose sexual division of labor was prevalent. Males tended to fish and hunt large game, perform ceremonies, trade, make weapons, and serve as warriors. Both sexes butchered meat, hunted small mammals, and processed animal skins. Females wove baskets, trapped, gathered firewood and edible plants, cooked, took care of children, and made clothing (Steponaitis 1986, Walthall 1980).

Following the Archaic period, the Woodland in north Alabama stretched from about 3200-1000 BP. Broken down further, the Early Woodland lasted from 3200-2400 BP, Middle from 2400-1700 BP, and Late from 1700-1000 BP (DeVore 2013). These prehistoric Native Americans created shell mounds in the Woodland period and followed many of the same activity patterns as the earlier Archaic groups. They differed in that they produced ceramics, the earliest of which were tempered with fiber or sand. There was greater social interaction and population size, gardening, a greater emphasis on mound building, and bow and arrow use (Anderson and Mainfort 2002; Blitz 1983, Culpepper 2012, Walthall and Jenkins 1976).

There are three pre-Mississippian groups that were included in this study (Long Branch, Flint River, and Bluff Creek) and one Mississippian group (Law's Site). These sites are outlined below.

*Long Branch.* Long Branch (1Lu67) is a 15-foot high shell mound site that was in use in the Middle to Late Archaic period. It was located in the Pickwick Basin, on the Tennessee River's northern bank in Lauderdale County, Alabama (about 15 miles from Florence) (Webb and DeJarnette 1942:178). A total of 93 burials were recovered, with mortuary patterns typical of shell mound sites, including round graves, partially flexed or extended internments, and cremations. Round graves were the most common at of these (43 were found) (Webb and DeJarnette 1942:183-185).

*Flint River.* Flint River (Ma48) is a shell mound site in Madison County, Alabama. It is located in the Wheeler Basin of the Tennessee River, at the point where Flint River empties into Tennessee River. The mound is thought to have had separate occupations during both the Late Archaic and Woodland periods, though burials from different periods were clustered when they were originally excavated (DeVore 2013). Two hundred and twelve burials were found in total (Webb 1939).

*Bluff Creek.* Bluff Creek (Lu59) is a 17-foot-deep shell mound site located in the Pickwick Basin, about 14 miles west of Florence in northwest Alabama. It lies about 1500 feet east of the mouth of Bluff Creek, in what Webb and DeJarnette (1942:95) describe as the creek's original flood plain, which has since become a floodplain for the Tennessee River. Unlike the former two sites, it is classified as multi-component, with both Archaic and Mississippian occupations. All of its dense shell layers contain evidence of small, shifting areas of temporary "camping," and frequent digging (Webb and DeJarnette 1942:104, 107). Silt strata point to several floods at the site (Lewis and Kneberg 1959:178). One hundred and ninety-seven individuals from separate occupations in the Archaic and Mississippian periods are buried in the mound. All five types of burials usually present in shell mounds in the Pickwick Basin are present (fully flexed, partially flexed, extended, seated, and partly cremated), and the burials within each type are uniform. Webb and DeJarnette (1942:106-107) suggest that this diversity in burial types represents multiple groups occupying the mound over time.

**The Mississippian Period.** The Mississippian period in Alabama ran from about 1000-450 BP (Early: 1000-800 BP, Middle: 800-650 BP, Late: 650-450 BP) (DeVore 2013). It brought with it shell tempered ceramics, maize agriculture, more intensive mound building, larger population sizes, a more sedentary lifestyle, and increased social complexity (Blitz 1993, Steponaitis 1983).

*Law's Site.* Law's Site (Ms100) is a Mississippian village site just north of McKee Island in the Guntersville Basin. It is located on the west side of Pine Island, about 2000 feet north of the island's southern end (Webb and Wilder 1951:136). Law's Site was overtaken by Lake Guntersville in 1939 (when the Guntersville dam was built) and is currently underwater. The site is thought to have been occupied continuously by Native Americans during the Gunterlands I-V horizons (c.8000-1000 BCE) and last occupied in the mid 1700s (Padgett 2006:32, Walthall 1980, Webb and Wilder 1951:44). The primary mode of subsistence is not known for this site, and it should be noted that, although Mississippian sites are typically associated with the presence of agriculture, Mississippian groups across regions can vary widely in terms of social complexity and subsistence (Bridges 1989b:386). However, based on the presence of agriculture in other Mississippian societies in the Southeast (including nearby Moundville), it is likely that agricultural activities took place at Law's Site during the Mississippian.

**Expected Activities.** Based on research at these and other shell mound sites from the Archaic and Mississippian periods, several types of activities involving the shoulders likely occurred that could have led to overuse injuries. For the pre-Mississippian (Archaic and Woodland) periods, these include digging, carrying heavy loads, fishing, harvesting shellfish, spear throwing, building structures, gardening, and processing meat and hides from deer and small mammals (Steponaitis 1986). Individuals from the Mississippian site likely performed many of the same activities, with the additions of using agricultural tools and tending to crops. This study, however, will not attempt to define which specific activities were most prevalent at the sites being studied based on particular injuries or injury patterns. As earlier critiques in the OA and EC literature have pointed out (Jurmain 1999), even when OA or EC is thought to be present due to an overuse injury, there are a variety of ways that overuse injury could have come about. Trying to narrow such injuries down to a single cause, in the absence of detailed ethnographic data to support it, would be unwise.

# CHAPTER 3. METHODOLOGY

## Materials and Methods

This study used a four-group posttest-only design with a sample size of 109. All qualifying individuals in the collection from each site were assessed. Individuals were drawn from four shell mound sites in north Alabama chosen for their temporal variability, geographic proximity to each other, and limited accessibility for future research. These sites include Long Branch (1Lu67) and Flint River (1Ma48) both Archaic sites, Bluff Creek (1Lu59), a multi-component site with both Archaic and Mississippian burials, and Law's Site (1Ms100), a Mississippian site.

To be considered complete enough for this study, individuals had to have at least 60 percent of one elbow articular surface and one shoulder articular surface present, and six of the entheses to be studied. Individuals were excluded for the following reasons:

1. If sex could not be determined
2. If the remains were commingled
3. If they had obvious pathologies affecting the arms besides OA and EC (such as seronegative spondyloarthropathies and diffuse idiopathic skeletal hyperostosis[7])
4. If they were missing the sacrum (necessary for some paleopathological diagnoses)
5. If their age at death was outside the range of 18-50 years

Individuals were assigned to one of two age cohorts, 18-34 or 35-50, because it has been suggested that age-related osteophytes begin developing after about age 35 and begin

[7] Villotte and Knüsel (2013:138) cite these pathologies as the most common to affect the entheses that are not caused by degenerative entheseal changes

accumulating rapidly after 50 (Cooper et al. 1994). Age-related EC begins developing for tendons between ages 30 and 35 (Bard 2003, Rodineau 1991), but the younger age cohort cap was left at 34 to allow for a large enough sample size.

Sex and age were estimated using standard osteological methods (Bass 1995, Brooks and Suchey 1990, Buikstra and Ubelaker 1994). Whenever possible, individuals were assessed for sex at the sciatic notch, pubis, preauricular sulcus, supraorbital ridge, nuchal area, mastoid process, mandible, and head of the femur, as is recommended in the sources above. Age was estimated based on dental eruption, epiphyseal closures, cranial suture closures, auricular changes, and pubic symphysis changes (Buikstra and Ubelaker 1994). Stature was estimated using the formulas for mongoloid male adults in Trotter (1970).

Each individual's shoulder and elbow joints were then assessed for osteoarthritic changes. The shoulder joint was chosen because it has been suggested that OA of the shoulder is usually the result of occupational stress in archaeological samples (Aufderheide and Rodríguez-Martín 1998). Elbow arthritis is also of interest because archaeological populations have been found to have a higher prevalence of elbow arthritis than modern groups (Aufderheide and Rodríguez-Martín 1998, Bridges 1992, Resnick 2002, Waldron 2009). Elbow OA is also thought to have less of a correlation with weight and age than other joints (Jurmain 1980). Articular surfaces on the clavicle, scapula, humerus, radius, and ulna were examined for the degree and extent of arthritic lipping, porosity, and eburnation. They also were examined for the presence of enthesophytes and other changes to the entheseal surfaces, including cysts, border irregularity, calcification, and bony production.

## Scoring Systems

A variety of criteria exist for diagnosing OA in dry bone (e.g., severity of osteophytes, lipping, porosity, and eburnation), and bioarchaeological studies have used several combinations of these criteria to diagnose OA (Jurmain 1999). The scoring system in Buikstra and Ubelaker (1994) was used for this study, as it is widely cited (Table 1, Figure 9). This system scores the extent and severity of several factors separately—lipping, surface porosity, and eburnation. Severe OA with eburnation was recorded separately from severe OA with or without eburnation to maximize comparability with other studies; however, only one eburnation-only case was found, so it was added in with other severe cases. Articular surfaces scored are listed in Table 2.

**Table 1.** Osteoarthritis scoring system (Buikstra and Ubelaker 1994:122-123)

| Criterion | Abbreviation | Values |
|---|---|---|
| Lipping degree | LD | 1: barely discernible,<br>2: sharp ridge or curved with spicules,<br>3: extensive spicule formation,<br>4: ankylosis |
| Lipping extent of circumference affected by most severe expression | LE | 1: <1/3,<br>2: 1/3-2/3,<br>3: >2/3 |
| Porosity degree | PD | 1: pinpoint,<br>2: coalesced,<br>3: both pinpoint and coalesced present |
| Porosity extent of surface affected | PE | 1: <1/3,<br>2: 1/3-2/3,<br>3: >2/3 |
| Eburnation degree | ED | 1: barely discernible,<br>2: polish only,<br>3: polish with groove(s)/impression(s) |
| Eburnation extent of surface affected | EE | 1: <1/3,<br>2: 1/3-2/3,<br>3: >2/3 |

**Figure 9.** Signs of osteoarthritis in the ulna and humerus, scored according to the Buikstra and Ubelaker (1994) system. Photo modified from Plomp et al. (2013:n.p.).

*Osteoarthritis in the proximal ulna (left) and the distal humerus (right). Scale is in tens of millimeters (0-50). The radial notch of the ulna (left) has marginal osteophytes (white arrow). Its lipping degree score would be three, and lipping extent score would be three. The capitulum of the humerus (right) shows eburnation (in circle) and pinpoint and coalesced porosity (in circle). Its score for porosity degree would be three; porosity extent would be three. Its eburnation degree score would be two; eburnation extent would be three.*

**Table 2**. Osteoarthritis scoring locations

| Bone | Joint | Articular surface location |
|---|---|---|
| Clavicle | Shoulder | Acromial facet |
| Scapula | Shoulder | Acromion |
| Scapula | Shoulder | Glenoid fossa |
| Humerus | Shoulder | Head |
| Humerus | Elbow | Trochlea |
| Humerus | Elbow | Capitulum |
| Radius | Elbow | Head |
| Ulna | Elbow | Radial notch |
| Ulna | Elbow | Trochlear notch |

For each individual, twelve fibrocartilaginous upper limb entheses were assessed on both sides of the body. Recent anatomical research has found fibrocartilaginous joints to be structurally different from fibrous joints (Benjamin et al. 1986, 2002, 2006; Benjamin and Ralphs 1998; Weiss 2015). More is known about how fibrocartilaginous entheses react to mechanical stress than is known for fibrous entheses, and they are thought to be more susceptible to overuse injuries (Benjamin et al. 2002:934, Weiss 2015). Thus, it has been recommended that bioarchaeologists restrict their studies of EC to fibrocartilaginous entheses until fibrous entheses and their response to stress are better understood (Davis et al. 2013, Shuler et al. 2012, Villotte et al. 2010a, Weiss 2015). Therefore, no fibrous entheses were included; all included entheses were determined to be fibrocartilaginous by Benjamin et al. (1986). For ease of comparison, the entheses to be assessed are the same as those measured in Shuler et al. 2012, and many of those also were assessed by Villotte et al. (2010). The entheses to be scored are listed in Table 3.

**Table 3.** Locations for scoring entheseal changes

| Bone | Location | Enthesis |
|---|---|---|
| Scapula | Supraglenoid tubercle | Origin of the biceps (long head) |
| Scapula | Infraglenoid tubercle | Origin of the triceps (long head) |
| Humerus | Proximal greater tubercle | Insertion of the supraspinatus |
| Humerus | Greater tubercle | Insertion of the infraspinatus |
| Humerus | Distal greater tubercle | Insertion of the teres minor |
| Humerus | Lesser tubercle | Insertion of the subscapularis |
| Humerus | Lateral epicondyle | Origin of the common extensors |
| Humerus | Medial epicondyle | Origin of the common flexors |
| Radius | Radial tuberosity | Insertion of the biceps brachii |
| Radius | Styloid process | Insertion of the brachioradialis |
| Ulna | Olecranon process | Insertion of the triceps brachii |
| Ulna | Ulnar tuberosity | Insertion of the brachialis |

Several scoring methods have been proposed in recent years for EC. The first to be used widely in the US was the Hawkey-Merbs system, which scores robusticity of muscle attachment sites, stress (pitting), and ossification (exotosis) (Hawkey and Merbs 1995). Despite its popularity, the Hawkey-Merbs system does not make the anatomical distinction between fibrocartilaginous and fibrous entheses (Davis et al. 2013, Hawkey and Merbs 1995). Because both entheses types are recorded together under the Hawkey-Merbs system, and bioarchaeologists cannot safely make assertions about fibrous entheses, data obtained using this system has limited reliability.

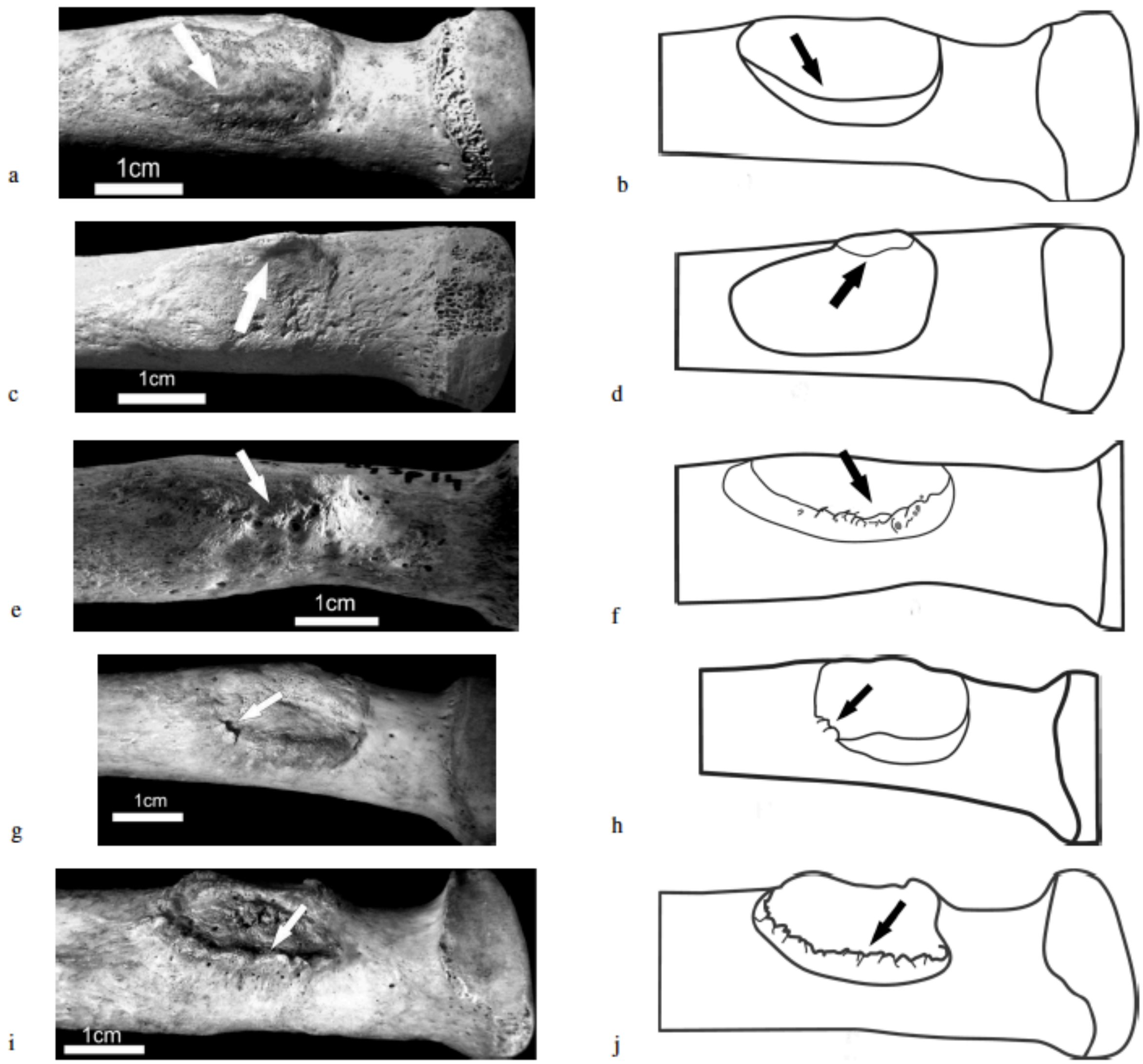
Only two scoring methods distinguish between enthesis types, the systems proposed by Villotte et al. (proposed in 2006, simplified in 2010) and Henderson et al. (2013, 2015). Both systems also report low inter- and intra-observer error (Davis et al. 2013, Henderson et al. 2015). The simplified scoring method by Villotte et al. (2010a) was used to score entheses in this study (Table 4, Figures 10 and 11). A score of 0 indicates a healthy enthesis with a "smooth, well-defined imprint on the bone, without vascular foramina, and with a regular margin" around the enthesis (Villotte et al. 2010a:226). A score of 1 indicates an entheseal change, as signaled by "irregularity" on the entheseal surface or a case in which "enthesophyte(s) are located at the outer part, and/or irregularity, foramina (at least three), cystic changes, calcification deposits, bony production, or osseous defect are found at the inner part" (Villotte et al. 2010a:226). The outer part of an enthesis refers to the border around the point of attachment, while the inner part refers to anything within the border. In this study, ECs were initially given scores of zero through three to specify the form of EC (for greater preservation of detail), and they were later simplified to scores of present or absent, as in Villotte et al. (2010a).

Another promising method for scoring entheseal changes is the newly developed Coimbra method (Henderson et al. 2013, 2015). This is the first method for scoring entheseal features separately, and it could allow researchers to examine the etiology of the individual features at fibrocartilaginous entheses. However, it is not feasible for this study because the authors do not yet have a way to train researchers en masse and recommend against learning the method from photos (Henderson et al. 2015).

**Table 4**. Entheseal change scoring system, expanded from Villotte et al. (2010a)

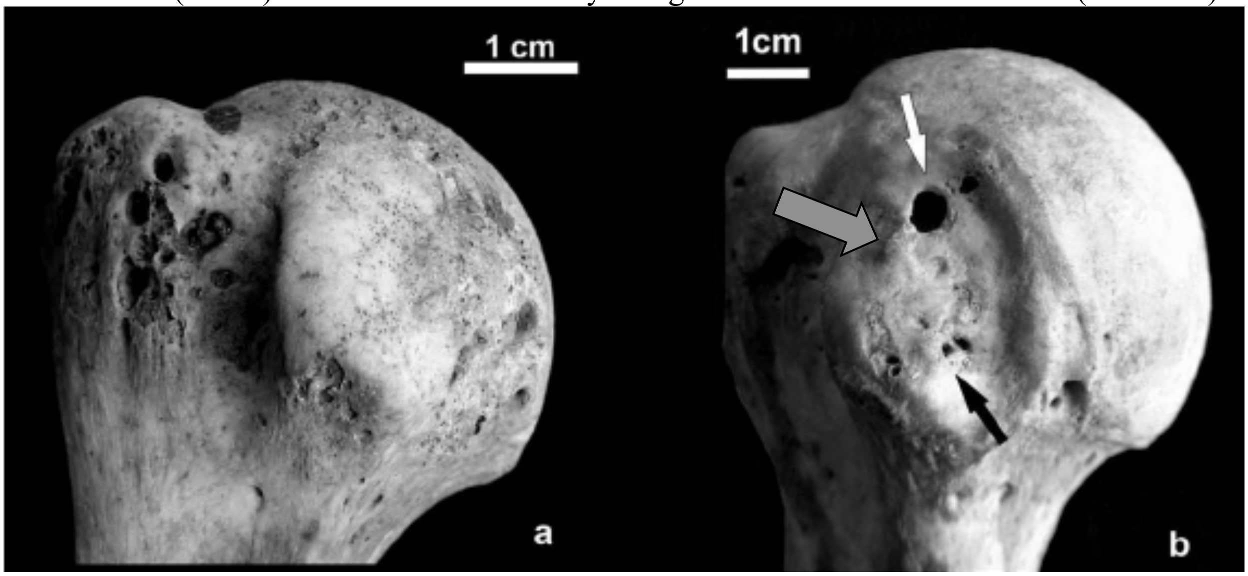
| Criterion | Abbreviation | Values |
|---|---|---|
| Entheseal change | EC | 0: EC not present/healthy enthesis—smooth well-defined imprint on the bone, < 3 vascular foramina, regular margin<br><br>1: irregularity or enthesophytes at the outer part<br><br>2: 3+ foramina and/or cystic changes at the inner part<br><br>3: calcification deposits, bony production, or osseous defect at the inner part |

**Figure 10.** Examples of outer-margin entheseal changes, scored according to the expanded Villotte et al. (2010a) criteria used in this study. Image from Villotte et al. (2006:72)




*Entheseal changes to the radial insertion of the biceps brachialis. A/B (two images of the same entheseal surface) show a healthy enthesis with a regular contour; these would receive a score of zero. C/D and G/H show each a raised bump (an enthesophyte) at the outer part of the enthesis; these would receive a score of one. E/F and I/J each show irregularities to the outer margin of the enthesis, which would also receive a score of one.*

**Figure 11.** Example of an inner-margin entheseal change, scored according to the expanded Villotte et al. (2010a) criteria used in this study. Image modified from Villotte et al. (2010:227).




*Entheseal changes to the humeral insertion of the subscapularis muscle. A shows a healthy enthesis, which would receive a score of zero. B shows an inner-margin cyst (white arrow), foramina (black arrow), and bony production (gray arrow); this enthesis would receive a score of two and three.*

**Analysis**

**Coding.** After data collection had concluded, all data were entered into SPSS version 24 for analysis (for coding information, see Appendices 1 and 2). When data was collected, it was recorded per specific joint location and side of the body. Analysis was simple for EC scores. For each enthesis and side, all of the following were recorded: percent completeness; a type score (1-3, signifying the type of EC); and a presence/absence score for EC. The final dichotomous variable proved to be the most useful for statistical analysis. For both OA and EC, the completeness variable was recorded primarily to ensure that no articular surfaces or entheses were scored that were less than 60 percent complete and was not used in the analysis.

For OA, the completeness of the articular surface or enthesis was recorded as a percentage, and ranked scores for lipping degree, lipping extent, porosity degree, porosity extent, eburnation degree, and eburnation extent were recorded. Recording the scores this way was necessary both to preserve the greatest level of detail possible and to allow for future comparisons with other researchers' work. However, leaving the scores in this format proved difficult for statistical analysis. To put the scores into a format that could be analyzed with chi squares and phi correlations, they were recoded into dichotomous variables. The OA score for each sided joint location (e.g., the OA score for the left clavicle's acromial facet) had to be broken down into separate variables. For example, separate variables were created for left side clavicle acromial facet OA that was absent (score of 0), mild (1), moderate (2), severe without eburnation (3), severe with eburnation (4), and severe with or without eburnation (5). Each variable could receive a value of zero (meaning no/false) or one (meaning yes/true). An articular surface or enthesis also had to meet specific requirements to qualify as a "yes" value for a given variable (see Appendix 2).

In addition to the original variables and recoded variables for OA and EC at specific articular surfaces and entheses, dichotomous yes/no variables were created for whole joint OA scores and whole joint EC scores to aid in interpretation. This was done by combining all shoulder OA variables into one, all elbow OA variables into one, all shoulder EC variables into one, and all elbow EC variables into one.

**Data Analysis.** Frequencies and measures of central tendency were found for the full sample. Chi square tests and phi correlations (with an alpha level of .05) were then run to find relationships among joint articular surfaces relating to hypotheses one, three, and four.

The chi-square is a non-parametric test for significant differences between groups. For data to qualify for a chi-square test, it must be in independent study groups (not paired), have categorical or ordinal variables, and have expected cell values of at least five (McHugh 2013). The other test, phi correlation, is based on the chi-square coefficient and measures the strength of association between two binary variables. It was designed for nominal data and is equivalent to Pearson's correlation but does not require continuous data. For this test, you must have two dichotomous variables, at least one of which is nominal (Chedzoy 2006). For both tests, the data I used was nominal (I tested scores of presence/absence, old/young, male/female, and right/left).

# CHAPTER 4. RESULTS AND DISCUSSION

## Sample Distribution

The individuals selected for inclusion in this study after all exclusions (n=109) represent a diverse sampling in sex, age, site, and time period, but were all from a relatively small geographic area (north Alabama) with similar environmental pressures. The sample split fairly evenly by sex and age—it was 48% male (n=52) and 52% female (n=57), as well as 58% young (n=63) and 42% old (n=46). Individuals from four shell mound sites are represented in this study, Long Branch (or 1Lu67, Archaic, northwest Alabama), Flint River (or 1Ma48, Archaic, northeast Alabama), Bluff Creek (or 1Lu59, multi-component, northwest Alabama), and Law's Site (or 1Ms100, Mississippian, northeast Alabama). The sample was split fairly evenly by site, with 20-30 individuals from each of the four sites; these included 30 from 1Lu67, 32 from 1Ma48, 27 from 1Lu59, and 20 from 1Ms100.

**OA Prevalence.** Joint-specific sample distributions are included in the table and graphs below (Table 5, Figures 12 and 13). It is important to note that, if a joint is listed as having OA, that means that OA was present in any of its component parts, which does not necessarily mean that OA was pervasive throughout the joint. Further, the nature of archaeological skeletal samples means that skeletons are often incomplete due to some bones being fragile and prone to being crushed (such as the scapula). Some skeletal remains might be incomplete because elements of the remains have been taken as trophies. Other remains might be altered by taphonomic processes, including those processes such as damage and movement by water or removal by animals. Therefore, statistics that list the bone surfaces positive for pathology as a percent of joints present at a given joint location are more telling than raw prevalence alone. Raw prevalence statistics will still be reported in order to provide a more full picture of the data.

The most common OA pathologies (as a percentage of joints present for that location) were as follows:

- left-side acromioclavicular (AC) OA (100%),
- any-side AC OA (94%),
- any-side shoulder OA (88%),
- right-side shoulder OA (85%), and
- right-side AC OA (80%).

The joint with the highest OA percent prevalence was the shoulder, more specifically, the AC joint on the left side. Further, AC joint OA made up 35 percent (89/257) of all OA found in the shoulders and elbows. Put another way, 19 percent of all joint locations studied for either pathology were positive for AC joint OA (89/426). In short, AC joint OA was surprisingly common in this sample compared to OA at the glenohumeral (GH) joint or elbow OA and compared to EC at all locations. For comparison, GH joint OA was found in 75 percent of GH joints; elbow OA was found in 77 percent of elbows. EC at all locations ranged from 60-92 percent.

For further perspective, Bridges' (1992) study of arthritis in the Americas found that upper limb joints usually had more OA on the right side of the body, though Mississippians in Alabama bucked this trend, having more left-side OA for both the shoulder and elbow (73). Also, a study of medieval Londoners (Waldron 1991b) found a high OA prevalence in the AC joint (65%, 28/43) as compared to other joints; in his study, though, the OA was less prevalent than in the present study and more evenly distributed across the right and left sides of the body.

**Figure 12**. OA prevalence, listed as the percent of joints positive for OA out of the total of the joint present at a particular location

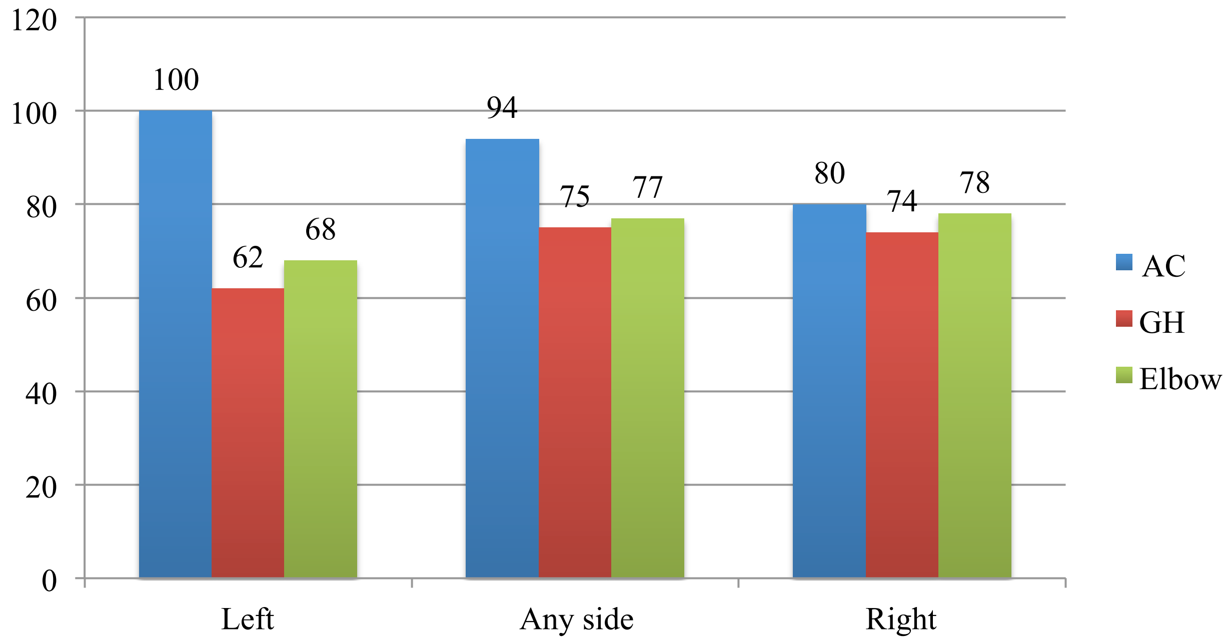



**Figure 13**. OA prevalence by raw totals, listed as the joints positive for OA out of the total joints present at a particular location

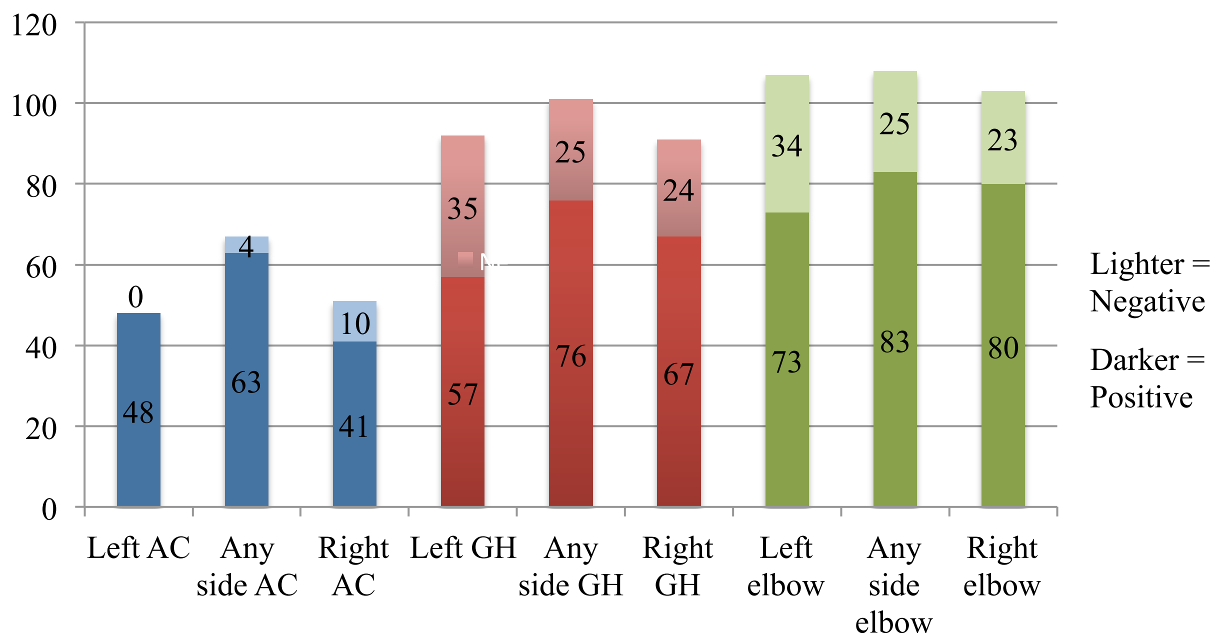


**Table 5**. Prevalence of OA or EC pathology at specific joint locations, out of the total joints present at a given location, for the full sample*

| Pathology | Joint | Side | Pathology prevalence / total joints present | Prevalence, percent of joints present |
|---|---|---|---|---|
| OA | Shoulder | Any | 91/103 | 88 |
| | AC | | 63/67 | 94 |
| | GH | | 76/101 | 75 |
| OA | Shoulder | L | 72/95 | 76 |
| | AC | | 48/48 | 100 |
| | GH | | 57/92 | 62 |
| OA | Shoulder | R | 79/93 | 85 |
| | AC‡ | | 41/51 | 80 |
| | GH§ | | 67/91 | 74 |
| OA | Elbow | Any | 83/108 | 77 |
| OA | Elbow | L | 73/107 | 68 |
| OA | Elbow | R | 80/103 | 78 |
| EC | Shoulder† | Any | 75/101 | 74 |
| EC | Shoulder | L | 52/87 | 60 |
| EC | Shoulder | R | 67/93 | 72 |
| EC | Elbow | Any | 100/109 | 92 |
| EC | Elbow | L | 92/109 | 84 |
| EC | Elbow | R | 95/106 | 90 |

* If OA or EC was present in any part of a joint, the joint was counted as having OA or EC.
†Shoulder EC includes only the GH joint because EC were only scored for tendons. The AC joint has no tendons used for shoulder movement.
‡ Acromioclavicular joint
§ Glenohumeral joint

**Table 6**. OA severity*

| Pathology | Joint | Side | Pathology prevalence, severe cases only** | Pathology prevalence, moderate cases only | Pathology prevalence, mild cases only | Pathology prevalence, moderate and severe cases | Pathology prevalence, mild, moderate, and severe cases |
|---|---|---|---|---|---|---|---|
| OA | Shoulder | Any | 39 (43) | 40 (44) | 12 (13) | 79 (87) | 91 |
| | AC† | | 36 (57) | 14 (22) | 13 (21) | 50 (79) | 63 |
| | GH‡ | | 6 (8) | 46 (61) | 24 (32) | 52 (69) | 76 |
| OA | Shoulder | L | 27 (38) | 28 (39) | 17 (24) | 55 (77) | 72 |
| | AC | | 24 (50) | 9 (19) | 15 (31) | 33 (69) | 48 |
| | GH | | 4 (7) | 27 (47) | 26 (46) | 31 (54) | 57 |
| OA | Shoulder | R | 26 (33) | 32 (41) | 21 (27) | 58 (74) | 79 |
| | AC | | 25 (61) | 7 (17) | 9 (22) | 32 (78) | 41 |
| | GH | | 3 (4) | 37 (55) | 27 (40) | 40 (59) | 67 |
| OA | Elbow | Any | 6 (7) | 46 (55) | 31 (37) | 52 (62) | 83 |
| OA | Elbow | L | 4 (5) | 34 (47) | 35 (48) | 38 (52) | 73 |
| OA | Elbow | R | 2 (3) | 34 (43) | 44 (55) | 36 (46) | 80 |

*Percent of all OA cases in parentheses
†Acromioclavicular joint
‡Glenohumeral joint

**OA Severity.** Many researchers only score OA if it is moderate, severe, or severe with eburnation. For that reason, this study collected severity data and initially separated out cases with eburnation. Only one case of shoulder or elbow OA was found with clear eburnation (though eburnation in the legs was observed in around a dozen individuals), so this case was included in the category "severe." See Appendix 2 for details on how categories were calculated.

Any shoulder OA (87%) had, by far, the highest percent of OA cases that were moderate to severe. The next highest were any AC joint OA (79%), right-side AC joint OA (78%), left-side shoulder OA (77%) (Table 6). This data tells a more complex story than the OA prevalences reported earlier would tell alone. Although OA was found in 100% of left-side AC joints that were present, a third of those cases were mild, meaning that when only moderate-to-severe cases are counted, cases this category becomes far less numerous. When only severe cases are counted, something even more interesting happens. Severe OA was rare in the elbows and GH joints (4-8%) but quite prevalent in the AC joints (50-61%). This supports what the OA prevalence data suggested, that AC joints bore the brunt of the OA burden.

**EC Prevalence.** The highest prevalences recorded for EC were all in the elbows (Table 5). Any elbow EC was found in 92% of the elbow joints present, with right elbow EC in 90% and left elbow EC in 84%. This is surprising—based on the OA results, which show the shoulder (particularly the AC joint) as more stressed, it would make sense for the shoulders to have the highest prevalence of EC, not the elbows. This conflict is likely attributable, at least in part, to the anatomy of the shoulder joints and what could be measured by OA scores versus EC scores. In this study, EC were scored only for tendons with fibrocartilaginous entheses. The AC joint has no tendons used for shoulder movement, so the only part of the shoulder scored for EC was the GH joint. In this sample, the AC joint was shown to hold the brunt of shoulder OA in both prevalence and severity; the GH joint had little OA—little stress—by comparison. If all the EC scores for the shoulder could measure were GH joint stress, it makes sense for them to have a lower prevalence than shoulder OA, which took into account both the AC and the GH joints.

**OA/EC Correlation Hypothesis**

Both OA and EC are currently used in bioarchaeology to examine occupational stress in the joints of skeletal populations. The primary task of this study was to question whether or not OA and EC are reliable skeletal stress indicators. As such, the first hypothesis assesses the relationship between the two pathologies: OA and EC at the same joint will positively correlate with each other for both joints studied. If OA and EC are both reliable indicators of skeletal stress, the two factors should show a positive correlation with each other at a given joint. In this study, for the full sample, OA and EC at the same joint showed no significant correlation with each other at either the shoulder or the elbow, so the hypothesis is rejected, with a caveat (Tables 7, 8, and 9). Shoulder OA did not correlate significantly with shoulder EC (p=.503), and elbow OA did not correlate with elbow EC (p=.868). In short, measures of stress in the form of OA and EC scores did not lead to the same conclusion about how much skeletal stress this sample endured.

The caveat, however, is the fact that AC joint stress could not be included in the shoulder EC variable like it was in the shoulder OA variable. The missing AC joint stress could be artificially lowering the amount of observable stress for the shoulder EC variable. In the elbow, OA and EC both contribute to the hypothesis being rejected, as they do not correlate with each other.

This lack of a significant correlation in shoulder or elbow variables suggests several possibilities. Either OA or EC, or both OA and EC, might not be reflective of skeletal stress, or they might not be equally sensitive to stress. Alternatively, the scoring methods used in this study might not accurately gauge the prevalence of OA or EC. Either way, given these results, it is hard to know for sure which joints in the populations studied were subject to the most wear and tear. It is also noteworthy that shoulder and elbow OA failed to correlate (p=.155), as did shoulder and elbow EC (p=.863).

At the site level, there was also no pattern for OA prevalence in relation to EC (Tables 8 and 9). For individuals within a single site (male, female, young, and old together), the percent of individuals with shoulder OA differed from the percent with shoulder EC by 10-49 percent, with the least difference at 1Lu59 and the most difference at 1Ma48. The difference in prevalence between shoulder OA and EC at a given site amount to 32 percent on average. For the elbow, rates of OA and EC differed by 4-36 percent within a site, with the least difference at 1Lu59 and the most difference at 1Ma48. Interestingly, both of the lowest differences in prevalence between OA and EC at a single joint (10% shoulder and 4% elbow) come from one site, Lu59. At that site, OA and EC line up fairly well. On the other hand, OA and EC prevalence line up especially poorly at another site, 1Ma48. Both of the greatest differences between OA and EC were found at this site, for both the shoulder and the elbow.

**Table 7.** Hypothesis one correlations*

| Group tested | Locations and pathologies | Valid cases | Chi-square (df) | Chi-square significance | Phi value | Phi coefficient significance |
|---|---|---|---|---|---|---|
| Full sample | Shou. OA x shou. EC | 100 | .503 (1) | .446 | .067 | .503 |
| Full sample | Elb. OA x elb. EC | 75 | .028 (1) | .868 | -.019 | .868 |
| Full sample | Shou. OA x elb. OA | 78 | 2.026 (1) | .155 | .161 | .155 |
| Full sample | Shou. EC x elb. EC | 70 | .030 (1) | .863 | -.021 | .863 |

*Shou. = shoulder, elb. = elbow, GH = glenohumeral
†Miss. = Mississippian
**df = degrees of freedom

**Table 8**. Pathology prevalence by site, sex, and age, out of total joints present*†

| Site | Shoulder OA | Shoulder EC | Elbow OA | Elbow EC |
|---|---|---|---|---|
| | | *All* | | |
| 1Lu67 | 18/27 (67) | 10/26 (39) | 15/30 (50) | 21/30 (70) |
| 1Ma48 | 18/29 (62) | 4/30 (13) | 18/31 (58) | 7/32 (22) |
| 1Lu59 | 11/26 (42) | 8/25 (32) | 14/27 (52) | 15/27 (56) |
| 1Ms100 | 14/20 (70) | 6/20 (30) | 7/18 (39) | 3/20 (15) |
| Total All | 61/102 (60) | 28/101 (28) | 54/106 (51) | 46/109 (42) |
| | | *Males* | | |
| 1Lu67 | 8/16 (50) | 7/16 (44) | 8/17 (47) | 14/17 (82) |
| 1Ma48 | 4/9 (44) | 3/10 (30) | 10/12 (83) | 4/12 (33) |
| 1Lu59 | 5/12 (42) | 1/11 (9) | 6/12 (50) | 5/12 (41) |
| 1Ms100 | 7/11 (64) | 5/11 (45) | 7/9 (78) | 0/11 (0) |
| Total Males | 24/48 (50) | 16/48 (33) | 31/50 (62) | 23/52 (44) |
| | | *Females* | | |
| 1Lu67 | 10/11 (91) | 3/10 (30) | 7/13 (54) | 7/13 (54) |
| 1Ma48 | 14/20 (70) | 1/20 (5) | 8/19 (42) | 3/20 (15) |
| 1Lu59 | 6/14 (43) | 7/14 (50) | 8/15 (53) | 10/15 (67) |
| 1Ms100 | 7/9 (78) | 1/9 (11) | 0/9 (0) | 3/9 (33) |
| Total Females | 37/54 (69) | 10/53 (19) | 23/56 (41) | 14/57 (25) |
| | | *Young* | | |
| 1Lu67 | 5/9 (56) | 1/9 (11) | 4/9 (44) | 6/9 (67) |
| 1Ma48 | 11/17 (65) | 0/18 (0) | 6/18 (33) | 5/19 (26) |
| 1Lu59 | 8/20 (40) | 7/20 (35) | 9/20 (45) | 11/20 (55) |
| 1Ms100 | 13/15 (87) | 3/15 (20) | 4/15 (27) | 3/15 (20) |
| Total Young | 37/61 (61) | 11/62 (18) | 23/63 (37) | 25/63 (40) |
| | | *Old* | | |
| 1Lu67 | 13/18 (72) | 9/17 (53) | 11/21 (52) | 15/21 (71) |
| 1Ma48 | 7/12 (58) | 4/12 (33) | 12/13 (92) | 2/13 (15) |
| 1Lu59 | 3/6 (50) | 1/5 (20) | 5/7 (71) | 4/7 (57) |
| 1Ms100 | 1/5 (20) | 3/5 (60) | 3/3 (100) | 0/5 (0) |
| Total Old | 24/41 (59) | 17/39 (44) | 31/44 (70) | 21/46 (46) |

*Percent affected by the pathology (out of the site's whole sample) is in parentheses
†Prevalence reflects any presence of the pathology on a person's arms (right arm, left arm, or both). If a person's right and left arms were affected, they were only counted once.

**Table 9**. Percent differences between OA and EC prevalence, by site*†

| Site | Shoulder OA | Shoulder EC | OA/EC difference (shoulder) | Elbow OA | Elbow EC | OA/EC difference (elbow) |
|---|---|---|---|---|---|---|
| 1Lu67 | 67 | 39 | 28 | 50 | 70 | 20 |
| 1Ma48 | 62 | 13 | 49 | 58 | 22 | 36 |
| 1Lu59 | 42 | 32 | 10 | 52 | 56 | 4 |
| 1Ms100 | 70 | 30 | 40 | 39 | 15 | 24 |
| Total All | 60 | 28 | 32 | 51 | 42 | 9 |

*Prevalence reflects any presence of the pathology on a person's arms (right arm, left arm, or both). If a person's right and left arms were affected, they were only counted once.
†All individuals with the relevant joints present are included (from both sex and age cohorts).

**Sub-sample Size Caveat**

For all of the findings to come (the results of the hypotheses on age, time period, sex, and symmetry), it is important to remember that the size of the full sample (n=109) is reduced when the sample is split by site, age, time period, or side of the body. For example, the shoulder OA samples for each site were between 20 and 29 individuals. If the sample is split twice, e.g., to analyze sex differences within a site, the sample size is reduced further, and findings should be considered merely suggestive; e.g., for shoulder OA among 1Ms100 females, the sample size is 9. This sub-sample size caveat is especially important for the results concerning 1Ms100, as it is the only Mississippian site represented. At the beginning of this project, an additional Mississippian site was set to be included in the analysis; however, it was excluded after the remains of its individuals were found to be badly water damaged. For most individuals, the joint surfaces were completely gone, which rendered scoring impossible. Unfortunately, due to the time-consuming nature of osteological analysis, small sample sizes are a frequent plague on bioarchaeological studies, and researchers are often left wishing for the time to include additional sites or individuals in their analyses. This holds true for the present study as well, and could be addressed by future research on additional sites.

### Age Differences Hypothesis

The second hypothesis states that OA and EC will be consistently associated with increasing age for both joints studied. Substantial differences between individuals in the younger and older cohorts were found for elbow OA (37% of young versus 70% of old) and shoulder EC (18% of young versus 44% of old). However, the scores for shoulder OA and elbow EC showed a difference of less than 7% between the young and old. These findings are confusing in that, if large differences were found, one would expect them to be found across EC variables only, or across OA variables only, or across shoulder variables only, or across elbow variables only. Instead, the large differences were found in elbow OA and shoulder EC. Further, in the case of shoulder OA, the young were affected slightly more frequently than the old (61% versus 59%). Therefore, the hypothesis is rejected. Neither OA nor EC was not found to increase consistently from younger to older individuals.

### Time Period Differences Hypothesis

The third hypothesis states that Mississippian individuals will likely display more OA and EC than pre-Mississippian individuals. The study found no consistent pattern of either increase or decrease in stress pathologies between pre-Mississippian groups (1Lu67 and 1Ma48) and the Mississippian group (1Ms100). For shoulder OA, the prevalence across the three sites is within eight percentage points. The two pre-Mississippian sites have 67 (1Lu67) and 62 percent (1Ma48) shoulder OA, while the Mississippian site has only a slightly higher prevalence at 70 percent (1Ms100). For elbow OA, the difference is only slightly higher than for shoulder OA. Elbow OA at the Mississippian site (39%) is within 11 percentage points of elbow OA at the pre-Mississippian sites (50% for 1Lu67 and 58% for 1Ma48). For shoulder EC, the Mississippian prevalence (30%) falls between those of the two pre-Mississippian groups (39% for 1Lu67 and

13% for 1Ma48). For elbow EC, the Mississippian group is only seven percentage points lower than the pre-Mississippian group 1Ma48. All of these findings serve to reject the hypothesis—no increased prevalence was found for OA or EC in Mississippian groups versus pre-Mississippian groups.

There were a couple of interesting findings about elbow EC; however, these do not affect the hypothesis. The 1Lu67 site was found to have an extremely high prevalence of elbow EC, with 70% overall (21/30) and 80% for males (14/17). These findings are interesting and suggest that these higher EC rates would be worth looking into in future studies, but the small sample sizes may limit the reliability of these findings. Also of interest is that the individuals from the more northwestern Alabama archaeological sites (1Lu67 and 1Lu59) were found to have much higher rates of elbow EC than the individuals from the more northeastern Alabama archaeological sites (1Ma49 and 1Ms100), even though the sites that were closer geographically were temporally separated; 1Lu67 had 70% and 1Lu59 had 56%, while 1Ma48 had 22% and 1Ms100 had 15%. Due to the temporal separation, these findings may be coincidental.

**Body Symmetry Hypothesis**

The fourth hypothesis states that the presence or absence of OA and EC will not vary significantly by side of the body. In the total sample, OA and EC prevalence did not vary significantly by side of the body consistently, so the hypothesis is confirmed. OA in the right and left shoulders showed significant correlations with each other ($p<.001$), as did OA in the right and left elbows ($p<.001$), EC in the right and left shoulders ($p=.002$), and EC in the right and left elbows ($p<.001$). Bilateral symmetry was most prevalent among individuals from Ma48, among the young, and among females.

**Table 10**. Hypotheses four and five correlations*†

| Group tested | Locations and pathologies | Valid cases | Chi-square (df) | Chi-square significance | Phi value | Phi coefficient significance |
|---|---|---|---|---|---|---|
| Full sample | R shou. OA x L shou. OA | 85 | 14.257 (1) | .000 | .410 | .000 |
| Full sample | R elb. OA x L elb. OA | 100 | 19.598 (1) | .000 | .443 | .000 |
| Full sample | R shou. EC x L shou. EC | 79 | 9.872 (1) | .002 | .354 | .002 |
| Full sample | R elb. EC x L elb. EC | 105 | 14.806 (1) | .000 | .376 | .000 |
| Full sample | Male shou. OA x female shou. OA | 102 | 3.635 (1) | .057 | .189 | .057 |
| Full sample | Male elb. OA x female elb. OA | 83 | 1.142 (1) | .285 | .117 | .285 |
| Full sample | Male shou. EC x female shou. EC | 75 | .887 (1) | .346 | .109 | .346 |
| Full sample | Male elb. EC x female elb EC | 100 | .003 (1) | .954 | .006 | .954 |

*Shou. = shoulder, elb. = elbow
†df = degrees of freedom

**Sex Differences Hypothesis**

The fifth hypothesis predicts that instances of OA and EC will show significant variation by sex. In the total sample, OA and EC showed less than 22 percent variation by sex. OA and EC prevalence was not significantly different based on sex for shoulder OA (p=.057), shoulder EC (p=..346), elbow OA (p=.285), or elbow EC (p=.954). The hypothesis is rejected; however, there were some striking sex differences at the site level.

In the 1Ms100 sample, 78% of males showed evidence of elbow OA, while no females did. At 1Ma48, 83% of males had elbow OA, while 42% of females did. At both of these northeast Alabama sites, males had a substantially greater prevalence of elbow OA than females.

For shoulder OA, on the other hand, the most striking sex differences favored females. At 1Lu67, males had a pathology prevalence of 50%, while females had 91%. At 1Ma48, 44% of shoulder OA cases were in males, while 70% were in females. At these pre-Mississippian sites, females had much higher rates of shoulder OA. This is surprising, given that Larsen (2002:134) has stated that a greater prevalence of joint OA in males is “nearly universal” in prehistoric societies and suggests that males had greater workloads and more mobility.

In the EC category, elbow EC was much more common for males at 1Lu67 with 82%, compared to 54% for females. At 1Lu59, shoulder EC was rare in males compared to females, with 9% compared to 50%. These findings would support the OA findings, in which males had more elbow pathologies, while females had more shoulder pathologies; however, the males with higher elbow OA and EC were not found at the same sites. Similarly, the females with higher shoulder OA and EC were not found at the same sites. It is important to remember that, when this sample is broken down by several factors—joint location, pathology, site and sex—sample sizes become quite small (e.g., only nine individuals are in the group for shoulder OA in 1Ma48 males), and findings should be considered in light of the sample size.

# CHAPTER 5. CONCLUSION

This study seeks to address inconsistencies in the current research on the meaning and reliability of osteoarthritis (OA) and entheseal changes (EC) in prehistoric populations. Most of the hypotheses in this study were rejected because, contrary to what the literature would suggest, OA and EC were not necessarily associated with increasing age, Mississippian agriculturalists did not have significantly more OA and EC than pre-Mississippian hunter-gatherers, and sex did not seem to make a difference in pathology prevalence. That is surprising, especially the age hypothesis, given how consistently, and forcefully in some cases, authors suggest age as the primary cause of OA and/or EC. Although there was ample data to reject hypotheses three (time period differences) and five (sex differences) in the context of this study, it is not recommended that the findings from these hypotheses be cited until the sub-sample sizes can be increased.

There was one more rejected hypothesis, and that one addressed the primary research question: Can you use two common measures of skeletal stress—OA and EC—together to assess an archaeological population's general activity level? Do they support each other's conclusions if used separately? Based on this study, the answer is probably not. There were no significant correlations between OA and EC prevalence at any of the studied skeletal joint locations. Both measures of joint stress are not accurate, but it is difficult to assess which measure is more accurate. Further research is needed to determine this. Also, because there were no substantial differences among sites for OA or EC levels, it was impossible to assess site-specific activity levels. This could mean that: 1. both OA and EC are inaccurate measures of skeletal stress, 2.

that either OA or EC is an inaccurate measure of stress, 3. that one of the two is more sensitive to stress, or 4. that the scoring systems used do not accurately reflect OA/EC prevalence.

To conclude, this is just one study, but it highlights the potential problem with interpreting skeletal stress from OA and EC. Here these two commonly used indicators of skeletal stress were shown to provide results that were often inconsistent with each other. Bioarchaeologists need to discover the differences between these two measures before they are used interchangeably as indicators of stress.

**Limitations**

Although the broad sample size for this study falls within the normal range for bioarchaeological studies, this study's within-site sample size (20-32) is its main limitation. It also is limited by the fact that it only compares one scoring system each for OA and EC. In spite of these limitations, this study provides a word of caution to bioarchaeologists using OA or EC as occupational stress markers—they might not be as reliable as was previously thought and more research is required to sort out inconsistencies.

**Future Research**

Expansions on this research could compare multiple scoring systems for both OA and EC to better understand whether there is a problem with using OA or EC as occupational stress indicators or whether there is a problem with the specific scoring systems that were used in this study. The sample area also could be expanded to include sites from a wider geographic area, perhaps the Southeast more broadly.

Another promising direction for OA and EC research is through zooarchaeology. While human skeletal collections with known occupations are difficult to come by, testing on animal skeletons with known activity patterns has proven fruitful and could prove to be more accessible.

Zumwalt (2005) compared the enthesis morphology of sedentary sheep against laboratory sheep whose muscles had been stressed by running on treadmills. She found no causal relationship between physical activity and enthesis morphology; however, the intensity of the sheep's exertion on the treadmills (running with weighted backpacks), the duration of each session (60 minutes per day with breaks), or the duration of the study (three months) could have been too small to see an effect on the entheses. The sample size also was small (n=20). All of these limitations could be rectified with an additional study. Niinimäki and Salmi (2014) also used animals to study EC. They evaluated an existing skeletal collection of reindeer that were known to be sedentary (they had lived in zoos) against free-ranging reindeer. They found that several flexor muscle sites were more robust in free-ranging reindeer (possibly from feeding behavior), though the difference only was significant among the heaviest reindeer. The insertion of the subscapularis was more robust in sedentary reindeer, possibly due to immobility and shoulder-bracing. As in the Zumwalt (2005) study, the sample size (n=53) was fairly small and could be expanded in future studies.

In addition to zooarchaeological studies, 3D scanning technology has shown promise for both OA and EC research, as it has the potential to eliminate some of the subjectivity required by current scoring systems and to open new avenues for analysis (see Noldner and Edgar 2013 for a good example). A last avenue for extending this research is to examine juveniles for early onset of OA or EC. This would not only eliminate age as a confounding factor for both pathologies, it would further the discussion on what causes OA and EC. It has been hypothesized that repetitive stress to the joints while they are developing might be more significant for joint degradation than stress that begins later in life (Burt et al. 2013). Studies have found increased OA in modern farmers who do heavy labor before age 16, milk livestock before age 20, or operate tractors before age 20. (Croft et al. 1992, Roberts and Manchester 2005, Thelin et al. 2004, Weiss and Jurmain 2007). It would be useful to know if this pattern holds true for prehistoric juveniles as well.

## REFERENCES


Alves Cardoso, F., and C. Henderson. 2010. "Enthesopathy Formation in the Humerus: Data from Known Age-at-Death and Known Occupation Skeletal Collections," *American Journal of Physical Anthropology* 141 (2010): 550–60.

Anderson, D. G., and R. C. Mainfort, Jr. *The Woodland Southeast*. Tuscaloosa, AL: University of Alabama Press, 2002.

Amato, J. "Index of Anatomy," Napa Valley College Anthropology, last modified August 19, 2013, http://www.jessicaamato.com/anatomy/Types_of_Joint_Articulations_Unlabeled_L.jpg.

Angel, J. L. "Osteoporosis: Thalassemia?" *American Journal of Physical Anthropology* 22 (1964): 369-73.

– – –. *Early Skeletons from Tranquility California*. Vol. 2, No. 1 of *Smithsonian Institution Contributions to Anthropology.* Washington, DC: Smithsonian Institution Press, 1966.

– – –. The People of Lerna. Washington DC: Smithsonian Institution Press, 1971.

Angel, J. L., J. Kelley, M. Parrington, and S. Pinter. "Life Stresses of the Free Black Community as Represented by the First African Baptist Church, Philadelphia, 1823-1841." *American Journal of Physical Anthropology* 74 (1987): 213–29.

Aufderheide, A. C., and C. Rodríguez-Martín. *The Cambridge Encyclopedia of Human Paleopathology.* Cambridge: Cambridge University Press, 1998.

Bard, H. "Physiopathologie, Reparation, Classification des Tendinopathies Mecaniques." In *Tendons et Entheses*, edited by H. Bard, A. Cotten, J. Rodineau, G. Saillant, and J. Railhac, 165–78. Montpellier, France: Sauramps Medical, 2003.

Bass, W. M. *Human Osteology: A Laboratory and Field Manual*. 4th ed. Special Publication No. 2. Columbia: Missouri Archaeological Society, 1995.

Benjamin, M., E. J. Evans, and L. Copp. "The Histology of Tendon Attachments to Bone in Man." *Journal of Anatomy* 149 (1986): 89-100.

Benjamin, M., and J. R. Ralphs. "Fibrocartilage in Tendons and Ligaments – An Adaptation to Compressive Load. *Journal of Anatomy* 193, no. 4 (1998): 481-494.

Benjamin, M., T. Kumai, S. Milz, B. M. Boszczyk, A. A. Boszczyk, and J. R. Ralphs.

"The Skeletal Attachment of Tendons—Tendon 'Entheses.'" *Comp Biochem Physiol A Mol Integr Physiol* 133, No. 4 (2002):931-45.

Benjamin M., H. Toumi, J. R. Ralphs, G. Bydder, T. M. Best, and S. Milz. "Where Tendons and Ligaments Meet Bone: Attachment Sites ("Entheses") in Relation to Exercise and/or Mechanical Load." *Journal of Anatomy* 208, No. 4 (2006): 471–90.

Bennett, G. A., H. Waine, and W. Bauer. *Changes in the Knee Joint at Various Ages*. New York: Commonwealth Fund, 1942.

Blitz, J. H. *Ancient Chiefdoms of the Tombigbee*. Tuscaloosa: University of Alabama Press, 1993.

– – –. "Pre-Mississippian Communities." In *Excavations in the Lubbub Creek Archaeological Locality*, Vol. 1, edited by Christopher Peebles, 128-39. Atlanta: Report submitted by the University of Michigan to the Heritage Conservation and Recreation Service, 1983.

Bradtmiller, B. "The Effect of Horseback Riding on Arikara Arthritis Patterns." Paper presented at the Annual Meeting of the American Anthropological Association, Chicago, 1983.

Bridges, P. S. "Bone Cortical Area in the Evaluation of Nutrition and Activity Levels." *American Journal of Human Biology* 1, No. 6 (1989a):785-92.

– – –. "Changes in Activities with the Shift to Agriculture in the Southeastern United States." *Current Anthropology* 30, No. 3 (1989b): 385–94.

– – –. *Changes in Long Bone Structure with the Transition to Agriculture: Implications for Prehistoric Activities.* PhD diss., University of Michigan, Ann Arbor, 1985a.

– – –. "Degenerative Joint Disease in Hunter-gatherers and Agriculturalists from the Southeastern United States." *American Journal of Physical Anthropology* 5 (1991a):378–91.

– – –. "Prehistoric Arthritis in the Americas." *Annual Review of Anthropology* 21 (1992): 67–91.

– – –. "Skeletal Evidence of Changes in Subsistence Activities Between the Archaic and Mississippian Time Periods in Northwestern Alabama." In *What Mean These Bones? Studies in Southeastern Bioarchaeology*, edited by M. Powell, P. Bridges, and A. Mires, 89–101. Tuscaloosa: University Alabama Press, 1991b.

– – –. "Structural Changes of the Arms Associated with the Habitual Grinding of Corn." *American Association of Physical Anthropologists* 66, no. 2 (1985b):149-150.

Brooks, S. T., and J. M. Suchey. "Skeletal Age Determination Based on the Os Pubis: A Comparison of Acsádi-Nemeskéri and Suchey-Brooks Methods." *Hum Evol* 5 (1990): 227–38.

Buikstra, J. E. “Biocultural Dimensions of Archeological Study: A Regional Perspective.” In *Biocultural Adaptation in Prehistoric America*, edited by R. L. Blakely, 67–84. Proceedings of the Southern Anthropological Society 11. Athens, GA: University of Georgia Press, 1977.

Buikstra, J. E., and R. E. Scott. “Key Concepts in Identity Studies.” In *Bioarchaeology and Identity in the Americas*, edited by K. J. Knudson and C. M. Stojanowski. Gainesville, FL: University Press of Florida, 2009.

Buikstra, J. E., and D. H. Ubelaker. *Standards for Data Collection from Human Skeletal Remains: Proceedings of a Seminar at the Field Museum of Natural History*. Arkansas Archaeological Report Research Series. Fayetteville: Arkansas Archaeological Survey, 1994.

Burkle-de la Camp, H. “Uber Meniscusschaden.” *Arch. Orthop. Unfallchir*. 37 (1937): 354-68.

Burt, N. M., D. Semple, K. Waterhouse, N. C. Lovell. *Identification and Interpretation of Joint Disease in Paleopathology and Forensic Anthropology.* Springfield, IL: Charles C. Thomas Publisher, 2013.

Campanacho V., and A. L. Santos. “Comparison of the Entheseal Changes of the Os Coxae of Portuguese Males (19th-20th Centuries) with Known Occupation.” *International Journal of Osteoarchaeology* 23, No. 2 (2012):229-36.

Capasso, L., K. A. R. Kennedy, C. A. Wilczak. “Atlas of Occupational Markers on Human Remains.” Journal of Paleontology Monographic Publications. Vol. 3. Terano, Italy: Edigrafital SPA, 1998.

Cardoso, F. A. “A Portrait of Gender in two 19th and 20th Century Portuguese Populations: A Paleopathological Perspective.” PhD diss., Durham University, 2008.

Cardoso F. A., and C. Y. Henderson. “Enthesopathy Formation in the Humerus: Data from Known Age-at-death and Known Occupation Skeletal Collections.” *American Journal of Physical Anthropology* 141 (2010):550-60.

Chapman, F. H. *Incidence of Arthritis in a Prehistoric Middle Mississippian Population*. Proceedings of the Indiana Academy of Science 72 (1962): 59-62.

Chedzoy, O. B. “Phi-coefficient.” In Vol. 9 of *Encyclopedia of Statistical Sciences*. Hoboken, NJ: John Wiley and Sons, 2006.

Churchill, S. E., and A. G. Morris. “Muscle Marking Morphology and Labor Intensity in Prehistoric Khoisan Foragers.” *International Journal of Osteoarchaeology* 8(1998): 390–411.

Cooper, C. T., D. McAlindon, D. Coggon et al. “Occupational Activity and Osteoarthritis of the Knee. *Annals of Rheumatic Diseases* 53(1994): 90-93.

Cook D. C., and S. P. Dougherty. "Row, Row, Row your Boat: Activity Patterns and Skeletal Robusticity in a Series from Chirikof Island, Alaska." *American Journal of Physical Anthropology Supplement* 32 (2001): 53.

Croft P., D. Croggon, M. Cruddas, and C. Cooper. "Osteoarthritis of the Hip: An Occupational Disease in Farmers." *British Medical Journal* 304 (1992): 1269-72.

Culpepper, L. E. "Manifestations of Arthritis through Time: Effects of Modes of Subsistence, Sex, and Age in the Prehistoric Mid-south." MA thesis, Mississippi State University, 2012.

Currey, J. D. "Effects of Differences in Mineralization on the Mechanical Properties of Bone." *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 304, No. 1121 (1984):509-18.

– – –. "The Design of Mineralized Hard Tissues for their Mechanical Functions." *Journal of Experimental Biology* 202 (1999): 3285-94.

Davis, M. "Odd Ailment: A Random Sampling of Strange Disorders, as Reported in American and British Medical Journals." *Discover* 2 (1981): 48-50.

Davis C. B., K. A. Shuler, M. E. Danforth, K. E. Herndon. "Patterns of Interobserver Error in the Scoring of Entheseal Changes." *International Journal of Osteoarchaeology* 23 (2013):147-51.

Devore, W. "Late Archaic Inter-Personal Violence in the Middle Tennessee Valley." PhD diss., University of Memphis, 2013.

Durigon, M. and J.-B. Paolaggi. "Enthese au Cours de la Vie. Pathologie des Insertions et Enthesiopathies." In *Pathologie des Insertions et Enthésopathies,* edited by L. Simon, C. Herisson, and J. Rodineau, 12-17. Paris: Masson, 1991.

Dutour, O. "Enthesopathies (Lesions of Muscular Insertions) as Indicators of the Activities of Neolithic Saharan Populations." *American Journal of Physical Anthropology* 71 (1986): 221-4.

Edynak, G. "Lifestyles from Skeletal Material: A Medieval Yugoslav Example." In *The Measures of Man*, edited by E. Giles and J. Friedlaender, 408–32. Cambridge: Peabody Museum Press, 1976.

Elsevier. "Publicaciones," last modified 2017. http://www.elsevier.es/ficheros/publicaciones/1699258X/0000000800000S2/v1_201305061530/S1699258X12002471/v1201305061530/en/main.assets/gr9.jpeg.

Eshed, V., A. Gopher, E. Galili, I. Hershkovitz. "Musculoskeletal Stress Markers in Natufian Hunter-gatherers and Neolithic Farmers in the Levant: The Upper Limb." *American Journal of Physical Anthropology* 123, No. 4 (2004): 303–15.

Fongemie, A. E., D. D. Buss, and S. J. Rolnick. “Management of Shoulder Impingement Syndrome and Rotator Cuff Tears.” *American Family Physician* 57, No. 4 (1998): 667-74.

Foster, A., H. Buckley, and N. Tayles. “Using Enthesis Robusticity to Infer Activity in the Past: A Review.” *Journal of Archaeological Method and Theory* 21 (2014): 511-33.

Gamble, J. G. *The Musculoskeletal System: Physiological Basics.* New York: Raven Press, 1988.

Gest, T. R., and Jaye Schlesinger. *MedCharts Anatomy*. New York: ILOC, 1995.

Godde, K., R. W. Taylor. “Musculoskeletal Stress Marker (MSM) Differences in the Modern American Upper Limb and Pectoral Girdle in Relation to Activity Level and Body Mass Index (BMI).” *Forensic Science International* 210, Nos. 1–3 (2011): 237–242.

Gray, H. *Anatomy of the Human Body*. 20th Edition. Revised by Henry Vandyke Carter. Philadelphia: Lea and Febiger, 1918.

Hayter, C. L., and R. S. Adler. “Injuries of the Elbow and the Current Treatment of Tendon Disease.” *American Journal of Roentgenology* 199 (2012): 546-57.

Hamilton, M. “Sexual Dimorphism in Skeletal Samples.” In *Sexual Dimorphism in Homo Sapiens*, edited by R. Hall, 107–64. New York: Praeger Publishers, 1982.

Havelková, P., M. Hladík, P. Velemínský. “Entheseal Changes: Do They Reflect Socioeconomic Status in the Early Medieval Central European Population? (Mikulčice – Klášteřisko, Great Moravian Empire, 9th-10th Century).” *International Journal of Osteoarchaeology* 23, No. 2 (2013): 237–51.

Havelková, P., S. Villotte, P. Velemínský, L. Polacek, and M. Dovisikova. “Enthesopathies and Activity Patterns in the Early Medieval Great Moravian Population: Evidence of Division of Labor.” *International Journal of Osteoarchaeology* 21, No. 4 (2010): 487-504.

Hawkes, S., C. Wells. “Crime and Punishment in an Anglo-Saxon Cemetery?” *Antiquity* 49 (1975): 118–22.

Hawkey, D. E. “Use of Upper Extremity Enthesiopathies to Indicate Habitual Activity Patterns.” MA thesis, Arizona State University, 1988.

Hawkey, D. E., and C. Merbs. “Activity-induced Musculoskeletal Stress Markers (MSM) and Subsistence Strategy Changes among Hudson Bay Eskimos.” *International Journal of Osteoarchaeology* 5 (1995): 324-38.

Hawkey, D. E., and S. Street. “Activity-induced Stress Markers in Prehistoric Human Remains from the Eastern Aleutian Islands.” *American Journal of Physical Anthropology* Supplement 14 (1992): 89.

Henderson C. Y., V. Mariotti, D. Pany-Kucera, S. Villotte, and C. Wilczak. "Recording Specific Entheseal Changes of Fibrocartilaginous Entheses: Initial Tests Using the Coimbra Method." *International Journal of Osteoarchaeology* 23, no. 2 (2013): 152–62.

– – –. 2015. "The New 'Coimbra Method': A Biologically Appropriate Method for Recording Specific Features of Fibrocartilaginous Entheseal Changes. International Journal of Osteoarchaeology." International Journal of Osteoarchaeology 26, no. 5 (2015): 925-32.

Herring S. A. and K. L. Nilson. 1987. "Introduction to Overuse Injuries." *Clinical Sports Medicine* 6: 225-39.

Hirschberg J. "Simulation of Mechanical Adaptations and Their Relationship to Stress Bearing in Skeletal Tissue." PhD diss., University of Western Australia, 2005.

Hough, A. J. Jr. "Pathology of Osteoarthritis." In *Arthritis and Allied Conditions,* 12th ed, edited by D. J. McCarty and W. J. Coopman, 1699-1721. Philadelphia: Lea and Febiger, 1993.

Hunter, D., and F. Eckstein. "Exercise and Osteoarthritis." *Journal of Anatomy* 214, No. 2 (2009): 197–207.

Jurmain, R. "The Pattern of Involvement of Appendicular Joint Disease." *American Journal of Physical Anthropology* 53, No. 1 (1980): 143–50.

– – –. "Degenerative Changes in Peripheral Joints as Indicators of Mechanical Stress: Opportunities and Limitations." *International Journal of Osteoarchaeology* 7 (1991): 247–52.

– – –. *Stories from the Skeleton: Behavioral Reconstruction in Human Osteology*. London: Taylor and Francis, 1999.

Jurmain, R., F. Alves Cardoso, C. Henderson, S. Villotte. "Bioarchaeology's Holy Grail: The Reconstruction of Activity." In *A Companion to Paleopathology*, edited by A. L. Grauer, 531–52. Oxford: Wiley-Blackwell, 2012.

Jurmain, R., and L. Kilgore. "Skeletal Evidence of Osteoarthritis: A Palaeopathological Perspective." *Annals of the Rheumatic Diseases* 54 (1995): 443–50.

Jurmain, R., and C. Roberts. "Juggling the Evidence: the Purported 'Acrobat' from Tell Brak." *Antiquity* 82 (2008): 318.

Jurmain, R., and S. Villotte. "Terminology: Entheses in Medical Literature and Physical Anthropology: A Brief Review." Document published online on 4 February, 2010, following the Workshop in Musculoskeletal Stress Markers (MSM): Limitations and Achievements in the Reconstruction of Past Activity Patterns*,* University of Coimbra, July 2-3, 2009. Coimbra, CIAS – Centro de Investigacao em Antropologia e Saude. Available from http://www.uc.pt/en/cia/msm/MSM_terminology3.pdf.

Kelley, J. O., and J. L. Angel. "Life Stresses of Slavery." *American Journal of Physical Anthropology* 74 (1987): 199-211.

Kennedy, K. A. R. "Skeletal Markers of Occupational Stress." In *Reconstruction of Life from the Skeleton*, edited by W. A. Isçan, and M. A. Krogman, 128-60. New York: Wiley-Liss., 1989.

– – –. "Markers of Occupational Stress: Conspectus and Prognosis of Research." *International Journal of Osteoarchaeology* 8, No. 5 (1998): 305-10.

Klaus, H.D., C. W. Larsen, and M. Tam. "Economic Intensification and Degenerative Joint Disease: Life and Labor on the Postcontact north Coast of Peru. *American Journal of Physical Anthropology* 139 (2009): 204–221.

Kliegman, R. M., B. F. Stanton, J. W. St Geme, and N. F. Schor. "Disorders Involving Cartilage Matrix Proteins." In *Nelson Textbook of Pediatrics*, edited by R. M. Kliegman, R. E. Behrman, H. B. Jenson, and B. M. Stanton. 20th ed. Philadelphia: Elsevier Health Sciences, 2007.

Knudson, K. J., and C. M. Stojanowski. "New directions in Bioarchaeology: Recent Contributions to the Study of Human Social Identities." *Journal of Archaeological Research* 16 (2008): 397-432.

Knüsel, C. J. "On the Biomechanical and Osteoarthritic Differences Between Hunter-gatherers and Agriculturalists." *American Journal of Physical Anthropology* 91, No. 4 (1993): 523–5.

Krieger, N. "Theories for Social Epidemiology in the 21st Century: An Ecosocial Perspective." *International Journal of Epidemiology* 30 (2001): 668-77.

Lai, P., and N. Lovell. "Skeletal Markers of Occupational Stress in the Fur Trade: A Case Study from a Hudson's Bay Company Fur Trade Post." *International Journal of Osteoarchaeology* 2 (1992): 221–34.

Larsen, C. S. *Aboriginal Subsistence Technology on the Southeastern Coastal Plain During the Late Prehistoric Period*. Gainsville, FL: University of Presses of Florida, 1980.

– – –. "Bioarchaeology: The Lives and Lifestyles of Past People." *Journal of Archaeological Research* 10, No. 2 (2002): 119-66.

– – –. "Biomechanical and Nutritional Environments in the Eastern Spanish Borderlands." In *Bioarchaeology of Native American Adaptation in the Spanish Borderlands,* edited by B. J. Baker and L. Kealhofer, 95-125. Gainsville: University Press of Florida, 1996.

Lawrence, J., and M. Sebo. "The Geography of Osteoarthritis." In *The Aetiopathogenesis of Osteoarthritis*, edited by G. Nuki, 155–83. Kent, UK: Pitman Medical, 1980.

Lewis, T. M. N. and M. Kneberg. "The Archaic Culture in the Middle South." *American Antiquity* 25, no. 2 (1959): 161-83.

Lieverse, A. R., V. I. Bazalliiski, O. I. Goriunova, A. W. Weber. Upper Limb Musculoskeletal Stress Markers among Middle Holocene Foragers of Siberia's Cis-Baikal Region. *American Journal of Physical Anthropology* 138 (2009): 458-72.

Lovell, N. "Spinal Arthritis and Physical Stress at Bronze Age Harappa." *American Journal of Physical Anthropology* 93 (1994):149–64.

Lovell, N., and A. Dublenko. "Further Aspects of Fur Trade Life Depicted in the Skeleton." *International Journal of Osteoarchaeology* 9 (1999): 248–65.

Lubsen, K. D. "What Trauma in Skeletal Remains Can Tell Us About Subsistence Activities During the Archaic: An Examination of the Burials at the Long Branch (1Lu67) and O'Neal (1Lu61) Sites." MA thesis, University of Alabama, 2004.

Mann, R., and D. Hunt. *Photographic Regional Atlas of Bone Disease: A Guide to Pathologic and Normal Variation in the Human Skeleton*. 3rd Edition. Springfield: Charles C. Thomas, 2005.

Mariotti, V., F. Facchini, and M. G. Belcastro. "Enthesopathies–Proposal of a Standardized Scoring Method and Applications." *Collegium Anthropologicum* 28 (2004): 145–59.

– – –. "The Study of Entheses: Proposal of a Standardized Scoring Method for Twenty-Three Entheses of the Postcranial Skeleton." *Collegium Anthropologicum* 31 (2007): 191-313.

McHugh, M. L. "The Chi-square Test of Independence." *Biochemia Media* 23, No. 2 (2013): 143-9.

Merbs, C. F. "Patterns of Activity-Induced Pathology in a Canadian Inuit Population." Archaeological Survey of Canada Paper, Mercury Series 119. Ottawa: National Museum of Man, 1983.

Meyer, C., N. Nicklisch, P. Held, B. Fritsch, and K. W. Alt. "Tracing Patterns of Activity in the Human Skeleton: An Overview of Methods, Problems, and Limits of Interpretation." *HOMO - Journal of Comparative Human Biology* 62, No. 3 (2011): 202–17.

Milella, M., M. G. Belcastro, C. P. E. Zollikofer, and V. Mariotti. "The Effect of Age, Sex, and Physical Activity on Entheseal Morphology in a Contemporary Italian Skeletal Collection." *American Journal of Physical Anthropology* 148 (2012): 379-88.

Miller, R. "Lateral Epicondylitis in a Prehistoric Central Arizona Indian Population from Nuvakwewtaga." In *Health and Disease in the Prehistoric Southwest*, edited by C. Merbs, R. Miller, and E. S. Dyer Alcauskas, 391–400. No. 34. Tempe: Arizona State University, 1985.

Molleson T., and D. Hodgson. "The Porters of Ur." *Isimu* 3 (2000): 101–117.

Molnar, P. "Patterns of Physical Activity and Material Culture on Gotland, Sweden, During the Middle Neolithic." *International Journal of Osteoarchaeology* 20, No. 1 (2008a): 1–14.

– – –. "Tracing Prehistoric Activities: Musculoskeletal Stress Marker Analysis of a Stone-Age Population on Island of Gotland in the Baltic Sea." *American Journal of Physical Anthropology* 129 (2006): 12-23.

– – –. *Tracing Prehistoric Activities: Life ways, Habitual Behaviour and Health of Hunter-Gatherers on Gotland*. Stockholm: Stockholm University, 2008b.

Molnar, P., T. P. Ahlstrom, and I. Leden. "Osteoarthritis and Activity—An Analysis of the Relationship Between Eburnation, Musculoskeletal Stress Markers (MSM) and Age in Two Neolithic Hunter–gatherer Populations from Gotland, Sweden." *International Journal of Osteoarchaeology* 21, No. 3 (2011): 283–91.

*Mosby's Medical Dictionary*. 10th ed. St. Louis: Elsevier, 2017.

Nagy, B. L. B. "The Life Left in Bones: Evidence of Habitual Activity Patterns in Two Prehistoric Kentucky Populations." PhD diss., Arizona State University, 2000.

National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMSD). "What Are Shoulder Problems?" last modified 2014, https://www.niams.nih.gov/Health_Info/Shoulder_Problems/shoulder_problems_ff.pdf.

– – –. "The Human Shoulder Joint," modified September 16, 2006, https://en.wikipedia.org/wiki/File:Shoulder_joint.svg.

Niinimäki, S. "What do Muscle Marker Ruggedness Scores Actually Tell Us?" *International Journal of Osteoarchaeology* 21, No. 3 (2011): 292–9.

– – –. "The Relationship between Musculoskeletal Stress Markers and Biomechanical Properties of the Humeral Diaphysis." *American Journal of Physical Anthropology* 147, No. 4 (2012): 618–28.

Niinimäki, S., and A.-K. Salmi. "Entheseal Changes in Free-Ranging Versus Zoo Reindeer—Observing Activity Status of Reindeer." *International Journal of Osteoarchaeology* 26, No. 2 (2014): 314-23.

Noldner, L. K., and H. J. Edgar "3D Representation and Analysis of Enthesis Morphology." *American Journal of Physical Anthropology* 152 (2013): 417–24.

Oates, J., T. Molleson, and A. Soltysiak. "Equids and an Acrobat: Closure Rituals at Tell Brak." *Antiquity* 82 (2008): 390–400.

Ortner, D. J. "Descriptions and Classifications of Degenerative Bone Changes in the Distal Joint Surfaces of the Humerus." *American Journal of Physical Anthropology* 28 (1968): 139-55.

Padgett, B. D. "Islands in the River of Time: The Bioarchaeology of Two Village Sites

(1MS32 and 1MS100) in Marshall County, Alabama, with New Interpretations of the Ethnohistorical and Archaeological Records." MA thesis, University of Alabama, 2006.

Palastanga, N., D. Field, and R. Soames. *Anatomy and Human Movement: Structure and Function.* 5th edition. Oxford: Elsevier, 2006.

Palmer, J. "Busy Bones: Osteoarthritis and Entheseal Changes as Evidence of Physical Activity and Social Differentiation in Post-Medieval the Netherlands." MA Thesis, University of Leiden, 2012.

Palmer, J. L. A., M. H. L. Hoogland, A. L. Waters-Rist. Activity Reconstruction of Post-Medieval Dutch Rural Villagers from Upper Limb Osteoarthritis and Entheseal Changes. *International Journal of Osteoarchaeology* 26, No. 1 (2014): 78-92.

Pfeiffer, S. "The Skeletal Biology of Archaic Populations of the Great Lakes Region." *Archaeological Survey of Canada*, paper 64 (1977):1-384.

Pickering, R. "Patterns of Degenerative Joint Disease in Middle Woodland, Late Woodland, and Mississippian Series from the Lower Illinois Valley." PhD diss., Northwestern University, 1984.

Plomp, K. A., C. A. Roberts, and U. Strand Vidarsdottir. "Morphological Characteristics of Healthy and Osteoarthritic Joint Surfaces in Archaeological Skeletons." *International Journal of Osteoarchaeology* (2013). Published online.

Quillen, D. M., M. Wuchner, and R. L. Hatch. "Acute Shoulder Injuries." *American Family Physician* 70, no. 10 (2004): 1947-54.

Resnick, D. "Degenerative Disease of Extraspinal Locations." In *Diagnosis of Bone and Joint Disorders*, 4th ed., edited by D. Resnick, 1271-381. Vol. 2. Philadelphia: Saunders, 2002.

Rhode, M. P. "Habitual Subsistence Practices among Prehistoric Andean Populations: Fishers and Farmers." PhD diss., University of Missouri-Columbia, 2006.

Robb, J.E. "The Interpretation of Skeletal Muscle Sites: A Statistical Approach." *International Journal of Osteoarchaeology* 8 (1998):354-77.

Roberts, C. and K. Manchester. *The Archaeology of Disease*. 3rd ed. New York: Cornell University Press, 2005.

Rodineau, J. "Pathogenie des Enthesopathies du Membre Superieur." In *Pathologie des Insertions et Enthesopathie*, edited by L. Simon, C. Herisson, and J. Rodineau, 166–71. Paris: Masson, 1991.

Rogers, J., L. Shepstone, and P. Dieppe. "Boneformers: Osteophyte and Enthesophyte Formation are Positively Associated. *Ann. Rheum. Dis.* 56 (1997): 85-90.

–––. “Is Osteoarthritis a Systemic Disorder of Bone?” *Arthritis and Rheumatology* 50, no. 2 (2004): 452-457.

Sanders, J. E., B. S. Goldstein, and D. F. Leotta. “Skin Response to Mechanical Stress: Adaptation Rather than Breakdown—A Review of the Literature. *Journal of Rehabilitation Research and Development* 32, no. 3 (1995): 214-26.

Schrader, S.A. “Bioarchaeology of the Everyday: Analysis of Activity Patterns and Diet in the Nile Valley. PhD diss., Purdue University, 2013.

Shuler, K. A., P. Zeng, M. E. Danforth. “Upper Limb Entheseal Change with the Transition to Agriculture in the Southeastern United States: A View from Moundville and the Central Tombigbee River Valley.” *HOMO - Journal of Comparative Human Biology* 63 (2012): 413-44.

Sokolof, L. *The Biology of Degenerative Joint Disease.* Chicago: University of Chicago Press, 1969.

Steponaitis, V. P. *Ceramics, Chronology, and Community Patterns: An Archaeological Study of Moundville*. New York: Academic Press, 1983.

–––. Prehistoric Archaeology in the Southeastern United States. *Annual Review of Anthropology* 15 (1986): 363-404.

Summit Disability Law Group. “Arthritis Disability,” last modified 2015. https://www.summitdisabilitylawgroup.com/disability-types/physical-disorders/arthritis.

Testut, L. *Recherches Anthropologiques sur le Squelette Quaternaire de Chancelade*. Lyon: Pitrat, 1889.

Thelin A., E. Vingard, and S. Holmberg. “Osteoarthritis of the Hip Joint and Farm Work.” *Am J Ind Med* 45 (2004): 202-9.

Trotter, M. “Estimation of Stature from Intact Long Limb Bones.” *Personal Identification in Mass Disasters,* edited by T. D. Stewart, 71-83. Washington DC: Smithsonian Institution Press, 1970.

Vilotte, S. “Current Medical Knowledge, Listing of Enthesopathy: A New Method (New Scoring System Based on this Enthesopathy of Medical Data).” *Bull Mem. Soc. Anthropol*. *Paris* 18 (2006): 65-86.

Villotte, S., D. Castex, V. Couallier, O. Dutour, C. J. Knüsel, and D. Henry-Gambier. “Enthesopathies as Occupational Stress Markers: Evidence from the Upper Limb.” *American Journal of Physical Anthropology* 142, No. 2 (2010a): 224–34.

Villotte, S., and C. J. Knüsel. “Comment on ‘Musculoskeletal stress marker (MSM) differences in the modern American upper limb and pectoral girdle in relation to activity level and body mass index (BMI)' by K. Godde and R. Wilson Taylor." *Forensic Science International* 217 (2012): e31.

– – –. "Understanding Entheseal Changes Definition and Life Course Changes." *International Journal of Osteoarchaeology* 23 (2013): 135-146.

Villotte S., S. E. Churchill, O. J. Dutour, and D. Henry-Gambier. "Subsistence Activities and the Sexual Division of Labor in the European Upper Paleolithic and Mesolithic: Evidence from Upper Limb Enthesopathies." *Journal of Human Evolution* 59, No. 1 (2010b): 35–43.

Waldron, T. *Paleopathology.* Cambridge: Cambridge University Press, 2009.

– – –. "The Prevalence of and the Relationship between some Spinal Diseases in a Human Skeletal Population from London." *International Journal of Osteoarchaeology* 1 (1991a): 103-110.

– – –. "Prevalence and Distribution of Osteoarthritis in a Population from Georgian and Early Victorian London." *Ann Rheum Dis* 50, No. 5 (1991b): 301-7.

Walthall, J. A. *Prehistoric Indians of the Southeast : Archaeology of Alabama and the Middle South.* Tuscaloosa: University Alabama Press, 1980.

Walthall, J. A., and N. J. Jenkins. "The Gulf Formational Stage in Southeastern Prehistory." *Southeastern Archaeological Conference Bulletin* 19 (1976): 43-49.

Webb, W. S. "An Archaeological Survey of Wheeler Basin on the Tennessee River in Northern Alabama." Smithsonian Institution, Bulletin 122. Washington DC: Bureau of American Ethnology, 1939.

Webb, D. C., and D. L. DeJarnette. *An Archaeological Survey of Pickwick Basin in the Adjacent Portions of the States of Alabama, Mississippi, and Tennessee*. Smithsonian Institution, Bulletin 1. Washington DC: Bureau of American Ethnology, 1942.

Webb, W. S., and C. G. Wilder. *An Archaeological Survey of Guntersville Basin on the Tennessee River in Northern Alabama*. Lexington: University of Kentucky Press, 1951.

Weiss, E. "Examining Activity Patterns and Biological Confounding Factors: Differences between Fibrocartilaginous and Fibrous Musculoskeletal Stress Markers." *International Journal of Osteoarchaeology* 25(2015): 281–8.

– – –. "Understanding Muscle Markers: Aggregation and Construct Validity." *American Journal of Physical Anthropology* 121 (2003): 230–40.

– – –. "Understanding Muscle markers: Lower Limbs." *American Journal of Physical Anthropology* 125 (2004): 232–8.

Weiss, E., and R. Jurmain. “Osteoarthritis Revisited: A Contemporary Review of Aetiology.” *International Journal of Osteoarchaeology* 17 (2007): 437–50.

Wells, C. *Bones, Bodies, and Disease: Evidence of Disease and Abnormality in Early Man*. New York: Praeger, 1964.

– – –. “The Radiological Examination of Human Remains.” In *Science in Archaeology*, edited by D. Brothwell and E. Higgs, 401–12. London: Thames and Hudson, 1963.

– – –. “Disease of the Knee in Anglo-Saxons.” *Medical and Biological Illustration* 15 (1965): 100–7.

White, T. D., M. T. Black, and P. A. Folkens. *Human Osteology.* 3rd edition. Oxford: Elsevier, 2012.

Wilczak, C. A. “Consideration of Sexual Dimorphism, Age, and Asymmetry in Quantitative Measurements of Muscle Insertion Sites.” *International Journal of Osteoarchaeology* 8, No. 5 (1998): 311–25.

Williamson, M. “A Comparison of DJD between Upland and Coastal Prehistoric Agriculturalists from GA.” In *Bioarchaeological Studies of Life in the Age of Agriculture: A View from the Southeast*, edited by P. Lambert, 134–47. Tuscaloosa: University Alabama Press, 2000.

Wolff, J. “The Law of Bone Remodeling,” translated from the 1892 original, “Das Gesetz der Transformation der Knochen,” by P. Maquet and R. Furlong. Berlin: Springer Verlag, 1986.

Zumwalt, A. “The Effect of Endurance Exercise on the Morphology of Muscle Attachment Sites. *The Journal of Experimental Biology* 209 (2005): 444-54.

## APPENDIX 1. SPSS CODES FOR VARIABLES

Codes used to represent variables and their values are listed below. Starting at variable 10, one joint location (the left clavicle at the acromial facet) is used to represent dozens of other joint location variables that are set up the same way (with slight modifications to their names to differentiate them).

| **VARIABLE NUMBER** | **VARIABLE DESCRIPTION** | **VARIABLE NAME** | **VALUES** | **VARIABLE TYPE** |
|---|---|---|---|---|
| 1 | Case ID number | CasID | Continuous | Continuous |
| 2 | Burial number | Burial | Continuous | Nominal |
| 3 | Site name | Site | Continuous | Nominal |
| 4 | Site number | SiteNo | Continuous | Nominal |
| 5 | Period | Period | 1. Archaic<br>2. Mississippian<br>3. Mixed | Ordinal |
| 6 | Sex | Sex | 1. Male<br>2. Female | Nominal |
| 7 | Age group | AgeGr | 1. Young<br>2. Old | Ordinal |
| 8 | Stature group | StatureGrW | 1. Short (lowest-162.7000)<br>2. Medium (162.7001-167.7000)<br>3. Tall (167.7001-highest) | Ordinal |
| 9 | Stature (ungrouped) | Stature | Continuous | Continuous |
| 10 | Left clavicle, acromial facet percent present | CL_AcfPer | Continuous | Continuous |
| 11 | Left clavicle, acromial facet lipping degree | CL_AcfLD | 1. barely discernable<br>2. sharp ridge or curved with spicules<br>3. extensive spicule formation<br>4. ankylosis | Nominal |
| 12 | Left clavicle, acromial facet lipping extent | CL_AcfLE | 1. <1/3<br>2. 1/3-2/3<br>3. >2/3 | Ordinal |
| 13 | Left clavicle, acromial facet porosity degree | CL_AcfPD | 1. pinpoint<br>2. coalesced<br>3. both pinpoint and coalesced present | Nominal |

| | | | | |
|---|---|---|---|---|
| 14 | Left clavicle, acromial facet porosity extent | CL_AcfPE | 1. <1/3<br>2. 1/3-2/3<br>3. >2/3 | Ordinal |
| 15 | Left clavicle, acromial facet eburnation degree | CL_AcfED | 1. barely discernable<br>2. polish only<br>3. polish with groove(s)/impression(s) | Nominal |
| 16 | Left clavicle, acromial facet eburnation extent | CL_AcfEE | 1. <1/3<br>2. 1/3-2/3<br>3. >2/3 | Ordinal |

## APPENDIX 2. SPSS FORMULAS USED TO CREATE SEVERITY VARIABLES

Cases were categorized as follows. The numbers in parenthesis represent the values for each trait that, in combination, makes up a severity variable (porosity degree, porosity extent, lipping degree, lipping extent, eburnation degree, eburnation extent). An example follows each severity variable to show the SPSS coding procedure that made up the calculated variable. The coding examples are from the left clavicle at the acromial facet (CL_Acf).

**OA absent**

- no OA traits >0

*SPSS coding for OA absent:*

- New variable = CL_AcfOAscore0
- Old and New Values = 0 thru Highest→0
- If = (CL_AcfPD + CL_AcfPE = 0) AND (CL_AcfLD + CL_AcfLE = 0) AND (CL_AcfED + CL_AcfEE = 0)

**Mild OA**

- (porosity degree + porosity extent = 4)
    - pinpoint (1) porosity on >2/3 (3) of surface
    - coalesced (2) porosity on 1/3-2/3 (2) of surface
    - both pinpoint and coalesced (3) porosity on <1/3 (1) of surface
- (porosity degree + porosity extent = 3)
    - pinpoint (1) porosity on 1/3-2/3 (2) of surface or
    - coalesced (2) porosity on <1/3 (1) of surface
- (lipping degree + lipping extent = 2)
    - barely discernable (1) lipping on <1/3 (1) of surface
- (lipping degree + lipping extent = 3) and (eburnation degree + eburnation extent = 0) and (porosity degree + porosity extent + lipping degree + lipping extent < 4)
    - barely discernable (1) lipping on 1/3-2/3 (2) of surface and no eburnation (0) and porosity and lipping categories together are <4

*SPSS coding for Mild OA:*

- New variable = CL_AcfOAscore1
- Old and New Values = 0 thru Highest--> 1
- If = ((CL_AcfPD + CL_AcfPE = 2) OR (CL_AcfPD + CL_AcfPE = 3)) OR ((CL_AcfLD + CL_AcfLE = 2) OR (CL_AcfLD + CL_AcfLE = 3)) AND (CL_AcfED + CL_AcfEE = 0) AND (CL_AcfPD + CL_AcfPE + CL_AcfLD + CL_AcfLE < 4)

**Moderate OA**

- (porosity degree + porosity extent = 4)

    - pinpoint (1) porosity on >2/3 (3) of surface
    - coalesced (2) porosity on 1/3-2/3 (2) of surface
    - both pinpoint and coalesced (3) porosity on <1/3 of surface
- (porosity degree + porosity extent = 5)
    - coalesced (2) porosity on >2/3 (3) of surface
    - both pinpoint and coalesced (3) porosity on 1/3-2/3 of surface
- (lipping degree + lipping extent = 4) and (eburnation degree and eburnation extent = 0) and (porosity degree + porosity extent + lipping degree + lipping extent = 4) or (porosity degree + porosity extent + lipping degree + lipping extent = 5)
    - barely discernable (1) lipping on >2/3 (3) of surface, and no eburnation (0), and porosity and lipping categories = 4 or 5
    - sharp ridge or curved with spicules (2) on 1/3-2/3 (2) of surface, and no eburnation (0), and porosity and lipping categories = 4 or 5
    - extensive spicule formation (3) on <1/3 (1) of surface, and no eburnation (0), and porosity and lipping categories = 4 or 5

*SPSS coding for Moderate OA:*

- New variable = CL_AcfOAscore2
- Old and New Values = 0 thru Highest--> 2
- If = ((CL_AcfPD + CL_AcfPE = 4) OR (CL_AcfPD + CL_AcfPE = 5)) OR (CL_AcfLD + CL_AcfLE = 4) AND (CL_AcfED + CL_AcfEE = 0) AND ((CL_AcfPD + CL_AcfPE + CL_AcfLD + CL_AcfLE = 4) OR (CL_AcfPD + CL_AcfPE + CL_AcfLD + CL_AcfLE = 5))

**Severe OA (eburnation included)**

- (porosity degree + porosity extent = 6)
    - both pinpoint and coalesced (3) porosity on >2/3 (3) of surface
- (lipping degree + lipping extent > 4) and (porosity degree + porosity extent + lipping degree + lipping extent > 5)
    - sharp ridge or curved with spicules (2) on >2/3 of surface (3), and porosity and lipping categories are >5
    - extensive spicule formation (3) on 1/3-2/3 (2) of surface, and porosity and lipping categories are >5
    - extensive spicule formation (3) on >2/3 (3) of surface, and porosity and lipping categories are >5
    - ankylosis (4) on any of the surface
- (eburnation degree + eburnation extent > 0)
    - barely discernable eburnation (1), polish only (2), polish with grooves/impressions (3) on any of the surface

*SPSS coding for Severe OA (eburnation included):*

- New variable = CL_AcfOAscore2
- Old and New Values = 0 thru Highest--> 2
- If = ((CL_AcfPD + CL_AcfPE = 4) OR (CL_AcfPD + CL_AcfPE = 5)) OR (CL_AcfLD + CL_AcfLE = 4) AND (CL_AcfED + CL_AcfEE = 0) AND ((CL_AcfPD + CL_AcfPE + CL_AcfLD + CL_AcfLE = 4) OR (CL_AcfPD + CL_AcfPE + CL_AcfLD + CL_AcfLE = 5))

**OA Present**

- Any OA traits >0

*SPSS coding for Present OA:*

- New variable = CL_AcfOAscore6
- Old and New Values = 0 thru Highest → 6
- If = (CL_AcfPD + CL_AcfPE + CL_AcfLD +CL_AcfLE + CL_AcfED + CL_AcfEE) > 0